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ANAEROBIC-AEROBIC LAGOON TREATMENT OF DAIRY MANURE WASTES

Donald E. Proctor

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ANAEROBIC-AEROBIC LAGOON TREATMENT OF DAIRY MANURE WASTES

by

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While manure could be hydraulically moved by high velocity flushing jets, it resulted in a slurry that was too thick to flow by gravity to catch basins within the cattle confinement areas. The anaerobic lagoon-activated sludge process sequence did accomplish overall pollutional strength reductions as high as 90%. The activated sludge process effluent was still too high in organic strength, color, and nutrients to be discharged to surface waters, however. Dissolved air flotation of algae cells produced in shallow propogation ponds was ineffective.

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ABSTRACT

The removal of manure from dairy cattle confinement areas by improved hydraulic flushing techniques was attempted in conjunction with an attempt to treat the resulting manure slurry in an anaerobic lagoon and activated sludge process. Algae cells were allowed to propagate in the activated sludge process effluent in an attempt to then harvest the cells and accomplish nutrient removal as a final polishing step.

While manure could be hydraulically moved by high velocity flushing jets, it resulted in a slurry that was too thick to flow by gravity to catch basins within the cattle confinement areas. The flushing technique would work quite well but was only effective if short flow distances were involved.

The anaerobic lagoon-activated sludge process sequence did accomplish overall pollutional strength reductions as high as 90%. The activated sludge process effluent was still too high in organic strength, color, and nutrients to be discharged to surface waters, however.

Dissolved air flotation of algae cells produced in shallow propagation ponds was, with one exception, quite discouraging. Only a small fraction of the suspended algae cells could be floated and the float itself would tend to collapse and release the algae at the surface of the flotation tank. The addition of coagulants and coagulant aids and the adjustment of pH resulted in only slightly improved recovery efficiency.

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SECTION I

CONCLUSIONS

1. The daily accumulation of manure cannot be flushed from paved dairy cattle confinement areas by high-velocity low-volume hydraulic jets or sprays unless the confinement slab area is:

   a. less than about 25 feet long measured in the direction of flushing jet travel, or
   b. significantly steeper in slope than confinement areas normally used.

   This conclusion is offered in spite of the fact that the high-velocity low-volume jets did accomplish a very rapid and thorough cleaning effect for travel distances up to about 25 feet. This cleaning was achieved with significantly less than 20 gallons of water usage per cow per day.

2. An anaerobic lagoon can remove and either retain or destroy a very significant fraction of the volatile solids and oxygen demanding constituents of hydraulically conveyed manure slurries. Because such slurries have an extremely high initial strength, the effluent or supernatant strength from the lagoon is not suitable for immediate reuse or discharge to surface water without additional treatment.

3. Odor and fly problems were not significant around the anaerobic manure slurry lagoon during operation of this project.

4. The anaerobic lagoon for this project was rendered inoperable by surface ice problems. This difficulty was encountered during an unusually long and severe winter period. It should be possible to overcome this problem even in normally severe winter areas by using a properly designed effluent withdrawal structure within the lagoon.

5. The activated sludge process was found to be capable of accomplishing 83% removal of the Chemical Oxygen Demand (COD) of anaerobic manure lagoon effluent or supernatant. While this fractional removal figure appears to be quite good, the quality of the process effluent would still not be suitable for discharge to surface waters. During the best periods of treatment, the effluent was invariably high in color, nitrate nitrogen, and phosphorus. It contained about 120 mg/1 of 5-day Biochemical Oxygen Demand (BOD_5).

6. The recovery of algal cells by dissolved air flotation as a means of nutrient removal from the aerobically treated manure waste did not appear to be successful except for one early day of operation. Percentage removal and float properties were both quite poor. Use

of coagulation-flocculation chemicals did not significantly improve the process.

7. The overall scheme of anaerobic lagoon treatment followed by activated sludge treatment followed by algal nutrient assimilation and harvesting did not appear to offer an acceptable solution to typical dairy manure disposal problems. Under circumstances of very limited alternatives, it is possible that anaerobic lagoons and activated sludge treatment in sequence could be acceptable.

SECTION II

RECOMMENDATIONS

1. When possible, operators of milk production herds and facilities should be encouraged to locate where land availability and other circumstances will permit manure disposal by environmentally acceptable land application of the manure. This could be accomplished by either hydraulic or mechanical manure conveyance systems and may require seasonal storage and scheduled application.

2. Further investigation of algae propagation and harvesting should be encouraged. In spite of the poor results encountered in this project, dissolved air flotation should not be totally dismissed as a possible means of harvesting or collecting algae.

SECTION III

INTRODUCTION

General Background

Changes in agricultural practices, coupled with changes in the living habits and aspirations of people in general, have resulted in the appearance of either new or intensified problems of environmental significance. Loehr (1, has discussed some of the changes in animal and crop practices that have altered the significance of animal manures relative to environmental quality. Other writers (2,3) have also explored cause and effect relationships that have intensified the environmental impact of livestock manures. Among the more important changes that apply to the dairy industry are: (a) agricultural specialization, (b) herd concentration and confinement, (c) competitive advantages for commercial fertilizers, (d) urban encroachment into rural areas, and (e) generally elevated aesthetic standards or expectations.

On the traditional diversified family farm, operations consisted of: (a) cultivation and harvesting of croplands and pastures, (b) feeding of some or all of the crops to one or more species of livestock, (c) the management and care of that livestock, (d) the sale of livestock or the marketing of meat, milk, eggs and/or wool, and (e) the return of livestock manure to the cropland that supported the endeavors. With the advent of specialization and concentration, the production of crops and the maintenance of livestock are often separated and, in some cases, separated by great distances. Both geographical and/or ownership separation discourages the application of manure to the cropland from which the livestock feed was harvested.

Confinement of large numbers of dairy cattle on comparatively small areas has had the encouraging benefit of reducing labor costs and increasing the efficiency of care and feeding. It has also increased the rate of excrement accumulation per unit area so that intentional management is now more necessary than when the same cattle spent a large fraction of each day grazing on fields and pasture. Commercial fertilizers that are now available have a competitive advantage over livestock manure because: (a) they are easily stored, transported, and applied to fields, (b) they can be formulated to rather exact nutrient content specifications, (c) they can be purchased and applied as needed, and (d) they do not present the possibility of introducing new weed seeds and plant pathogens.

Urban "sprawl" or encroachment tends to bring more people, who are not necessarily sympathetic toward the dairyman's problems, into closer contact with the dairy farm environment. All segments of the population have an increased awareness of, and concern for, the quality of the natural environment. Many of the individuals do not relate the availability and economy of agricultural products to their total environment

to the same extent they relate agricultural pollutants to the natural environment. Most of us, including the dairyman himself, are less tolerant to environmental degradation than we were only one decade ago. Finally, an increasing population, with an increasing standard of living, exerts an increasing demand for agricultural products which tends, in turn, to increase the amount of dairy manure produced. Though the total number of operating dairies and the total number of dairy cows appears to be decreasing; the average cow now eats more, produces more milk, and excretes more feces and urine.

In summary then, we have more and more manure of less and less value accumulating faster and faster on less and less land in ever closer proximity to an increasing number of less tolerant people.

When a problem is defined and a solution is proposed, it is important that criteria be established which can be used to measure the degree of success. In the case of problems associated with dairy manure, the criteria for success evaluation should at least include the following:

1. Effectiveness - To what extent does a proposed solution provide actual or ultimate disposal of the manure? It is seldom sufficient to simply transfer the manure to a new location where it will accumulate to generate new problems.

2. Dependability - Will the proposed solution be effective on a year-around basis and under all reasonably expected conditions? Would a process breakdown, for whatever reasons, create serious consequences or insurmountable problems. We cannot "turn-off" the dairy for a few days until emergency repairs are accomplished.

3. Costs - Do the capital and operating cost requirements of the proposed solution allow a residual profit to serve as a motive for continued operation of the dairy? Ideally, the proposed solution should result in a reduction of net total operating costs. If net operating costs will increase, can such incremental costs be covered by passing them on to the consumers of the dairy products?

4. Environmental Acceptability - Does the proposed solution accomplish manure disposal but only at the expense of environmental degradations that will impact upon the farmer, his dairy herd, his immediate neighbors, or society in general? Environmental quality control problems could include organic, nutrient, color, or odor pollution of ground or surface waters; odor, aerosol, or dust contamination of air; fly, other insect, or other vector problems; disease transmission within the herd, to man, or to other animals; deterioration of aesthetic land values; or reduction of field productivity because of the introduction of weed seeds, plant pathogens or from alteration of soil properties.

There is no common scale upon which all of these criteria can be measured. Relative priorities will vary depending upon the individual circumstances of each case and upon who is doing the evaluation of any proposed solution.

Dairy Manure Amounts and Composition

The volume and qualitative characteristics of dairy manure varies quite significantly from one operation to another and may vary appreciably from one season to another. The number of cows in the herd, the breed and size of cows, the type of feed, the confinement circumstances, the bedding (if any) used, and the weather are all factors that influence the amount and/or characteristics of the manure problem. On many dairy farms, the milking herd is no longer placed on pasture land for any fraction of the day but are continuously held in concentrated confinement pens. These pens may be totally or partially paved and totally or partially roofed. Even maturing heifers and non-lactating mature cows are similarly confined at some dairies. This means that all urine and feces are excreted on a relatively small area rather than an appreciable fraction being naturally dispersed over the much larger pasture area. If rainfall and snowmelt water are not excluded by roof, eave trough, and storm drain systems, it adds materially to the annual volume of manure slurry and to the day-to-day variability in volume.

The composition and physical characteristics of dairy manure is materially affected by the diet or ration. Cows fed largely on fresh cut green forage, on green pasture, or on moist silage tends to be more fluid than that of cows fed on dry hay and grain rations. In almost all cases, the diet includes enough non-grain plant material so that the manure contains a significant amount of fibrous material composed of lignious-cellulosic material which escapes through the complex ruminant digestive system of the cows. In addition, varying amounts of hay or roughage and some bedding material get spilled or mixed in with the manure. The amount varies quite significantly depending upon how the confinement areas are arranged and managed, and upon how the feeding facilities are constructed and operated.

Water from urine and watering trough spillage may be largely evaporated away in dry weather or increased by precipitation in wet weather. The effect of evaporation may be affected by the slope and texture of the confinement area surfaces. Water content and manure fluidity is drastically altered, of course, if the confinement areas are cleaned by hydraulic flushing methods instead of by mechanical scrapers and loaders.

Recognizing that both volume and composition of manure removed from a dairy cattle confinement area are highly variable, some general average values can be given for fresh excrement. The total weight (feces + urine) should be in the neighborhood of 60 to 90 lbs./cow-day (25 to 40 kg./cow-day) of which 80 to 90 percent is moisture. Total solids should range from 9 to 15 lbs./cow-day (4 to 7 kg./cow-day) on a dry weight

basis. These solids will probably be about 75 to 85% volatile. While the manure is certainly biologically degradable enough to be a noxious substance, it does contain a significant amount of volatile matter that degrades only slowly. The 5-day BOD (Biochemical Oxygen Demand) is on the order of 1.2 to 1.6 pounds/cow-day (500 to 700 g./cow-day) or 0.12 to 0.18 parts BOD per 1.0 part volatile matter. Chemical oxidizability is such that the COD (Chemical Oxygen Demand) to volatile solids ratio approaches, or perhaps exceeds, 1.0. Although variable, the total nitrogen content (largely in the form of organic and ammonia nitrogen) will usually be somewhere between 0.35 to 0.45 lb./cow-day (160 to 200 g./cow-day). Phosphorous, expressed as P_2O_5, will usually be slightly above 0.1 lb./cow-day (45 g./cow-day).

The amount and composition of dairy manure is such that it must be regarded as a potentially significant pollutant. In water, it can exert a very high oxygen demand; it can deposit organic solids to form septic sludge deposits; it can supply floating residues and color bodies to degrade aesthetics; it can supply the necessary nutrients to support eutrophication processes; it can introduce organisms of the coliform group to cause high bacterial indicator counts; and it can be a source of organisms that are pathogenic to man. If allowed to accumulate, dairy manure can decompose to generate odors, it can support fly and other insect propogation, it can be leached by precipitation to contribute pollutants to surface or ground waters, it can dry out to contribute windblown dust, or it can detract from aesthetic quality. On the other hand, manure can be utilized on land for the fertilizer value of its nutrient content or for the build up of humus in low organic soils. Basically then, dairy manure can constitute a serious liability or a modest asset depending upon both circumstances and choice.

Treatment-Disposal Options

A wide range of techniques for treatment and/or disposal of dairy manure has been, or may be, considered. The treatment-disposal process spectrum ranges from direct complete return of all excrement to farm land at one extreme to high pressure, wet combustion at the other. No single treatment and/or disposal scheme could be expected to be best, or even acceptable, for all circumstances. Unfortunately, there probably are some dairies governed by circumstances such that no treatment and/or disposal scheme can be both economically and environmentally acceptable. In that case, the difficult choice must be made between moving, ceasing operations, or disregarding the environmental consequences of the operation.

Returning the manure and its nutrient content back to productive cropland is probably the most environmentally acceptable practice when this is possible. Certainly there will be some instances where the costs of such manure management are not offset by the fertilizer or soil amendment benefits. This still may be the least costly and/or most acceptable method of manure disposal, however. It may be necessary to stockpile the manure, either in solid or liquid slurry form, during some seasons

in order to schedule the land application to coincide with weather or land use requirements (4).

There may be operational circumstances such that manure disposal on cropland is either impossible or undesirable for one or more reasons. Some dairy operations are so specialized as to have an inadequate area of land for manure disposal. Either no land is available or available land is unsuitable because the current usage is not compatible with the application of manure. Frequent rainfall and runoff may preclude land application of manure at least during some seasons.

Additional possible treatment-disposal techniques that have been, or might be, considered for dairy manure are: conversion into by-products such as wallboard or fuel briquettes, reprocessing as secondary livestock feed, burial, drying and marketing through garden supply outlets, drying and incineration, high pressure wet combustion, anaerobic digestion, anaerobic lagoons, aerobic lagoons, anaerobic-aerobic processes in series, modifications of activated sludge treatment, and trickling filters. The variety of factors to be considered in process selection is beyond the scope of this report introduction but, as already stated, no single scheme can possibly be best in all cases.

Handling all, or at least a portion, of the excrement wastes from dairy cattle confinement areas in liquid form offers several advantages at many dairies. Some have elected to use a large volume of water at low pressure or even in non-pressurized gravity flow across the confinement area. Where the facilities have been constructed or modified with gravity flushing in mind, this practice does appear to provide a very acceptable degree of sanitation in the confinement areas. Unfortunately, such systems may use 200 or more gallons (750 liters) of water per cow-day. This makes either treatment or storage of the resultant manure slurry quite difficult. If year-around application of slurry to cropland is possible, however, and not adversely affected by the additional water volume, this method of flushing should be quite acceptable. The resulting dilute slurry could be settled to remove most solids and the bulk of the water reused in such high volume flushing schemes. This reuse may introduce problems of disease transmission and odor control.

Some dairies use mechanical scrapers to remove the bulk of the manure solids and then complete the confinement area cleaning process by rinsing the slab with water from hoses and nozzles. This reduces the volume of water but only at the expense of additional labor costs over and above the labor for the mechanical scraping and loading.

General Project Background

Washington State University, prior to the development of the project reported here, had been engaged in several activities related, directly or indirectly, to the problems of manure management. Within the College of Agriculture, the Department of Animal Sciences maintained livestock

at several different sites or stations. These operations were for both research and instructional objectives and involved both breed improvement and nutritional studies. Beef cattle, dairy cattle, poultry, swine, sheep and horses were maintained either at on-campus or off-campus facilities.

One such off-campus operation was at the J. C. Knott Dairy Research Center on the C. Y. Young Family Farm located about three miles south and west of the Washington State University campus. From 100 to 170 head of dairy cattle, of several breeds, were maintained at this farm. Some heifers and non-lactating mature cows were allowed to graze on pasture but the producing herd was continuously held in paved confinement areas at the building complex of the farm. (Figure 1).

A manure disposal research project had been initiated in 1961 at the Knott Dairy Research Center. The Department of Animal Sciences, the Department of Agricultural Engineering, and the Sanitary Engineering Section of the Division of Industrial Research of the College of Engineering (now Engineering Research Division) had cooperatively developed plans for a series of lagoons to receive runoff liquor, including some intentionally applied flushing water, from the paved confinement area.

Figure 1 shows the layout of the herd confinement and service facilities in the upper left corner. The confinement area drainage line and the various lagoons are also shown in Figure 1. The lagoon studies had involved two parallel schemes for anaerobic-aerobic lagoons in series. Runoff rainwater, urine, or flushing water from the confinement area could be directed through gravity lines to flow to Lagoon #1 and on to either Lagoon #3 or Lagoon #4. Alternatively, the confinement area flow could be directed to Lagoon #2 and then to either Lagoon #3 or #4. Lagoons #1 and #2 had been intended to be loaded anaerobically, Lagoon #3 was expected to fluctuate between anaerobic and aerobic depending upon selected loading, and Lagoon #4 was intended to be aerobic at all times. The research efforts relative to evaluating the performance of the manure lagoons had been limited by available time and monitoring capability. Some measure of lagoon effectiveness was reported (5), however.

There was approximately 42,000 sq. ft. (3,900 sq. m.) of cattle confinement area which included about 17,000 sq. ft. (1,580 sq. m.) of bedded area. The arrangement of the paved confinement area, building roofs, and some pavement outside the confinement area fences collected precipitation from about 45,000 sq. ft. (4,200 sq. m.) to be discharged through the catch basins of the confinement area. While most of the roof sections were equipped with eave troughs and down spouts, the runoff still discharged onto the confinement slab. Such roof drainage was, therefore, added to the volume of any urine or flushed manure slurry being conveyed through the gravity drain system.

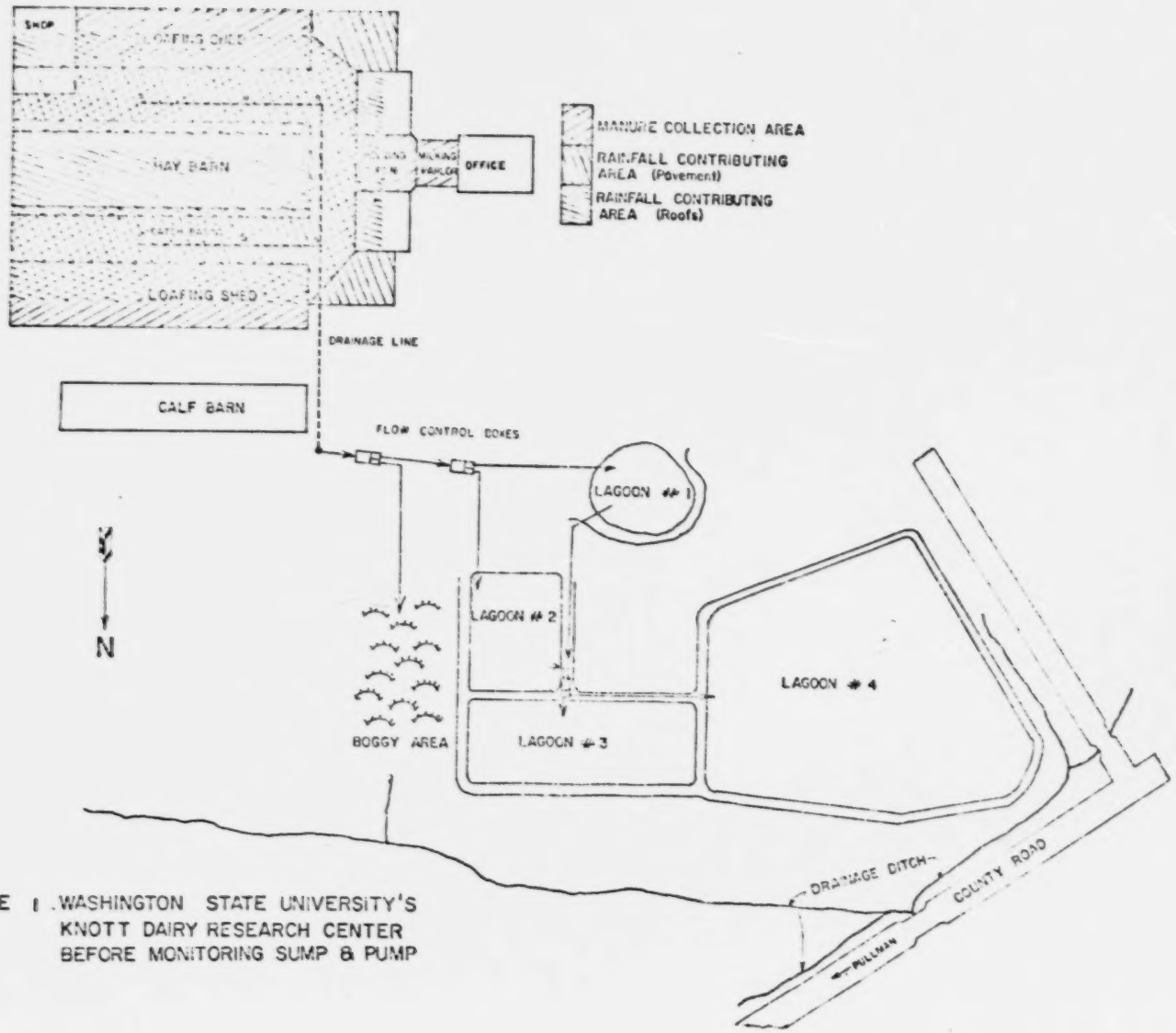

FIGURE 1. WASHINGTON STATE UNIVERSITY'S KNOTT DAIRY RESEARCH CENTER BEFORE MONITORING SUMP & PUMP

The confinement slab catch basins were covered with cast iron grates. The drain lines were mostly of 8-inch (20-cm.) diameter concrete tile but did contain a short section of 12-inch (30-cm.) diameter corrugated metal pipe. This line extended to a flow control-gaging box near the northwest corner of the calf barn. The control box provided alternate V-notch weirs discharging to either of two continuing lines. One line discharged down a short steep hill to a boggy area where solids could accumulate and water could seep away. The other line proceeded at a slight slope (about 0.02) to a second similar control-gaging box with alternate V-notch weirs discharging to either lagoons L-1 or L-2.

The control-gaging or "splitter" boxes had proven to be inadequate for obtaining either flow or slurry composition data for several reasons. First, the stringy solids of the slurry tended to bridge across the bottom of the V-notches or to get stranded on the sharp crest of the weirs. The head-discharge weir calibration was seldom accurate, therefore. The chamber just upstream from the weir plates allowed sedimentation of grit and heavy organic solids in the box and upstream drain line which drastically altered the geometry of the inlet channel and approach to the weirs. The flow from the confinement area was quite variable even during an actual period of flushing. Runoff precipitation could occur at any time of day or night, of course, and such flows necessarily went ungaged. No head or stage recorders were provided for either control box.

To overcome the problems of inadequate flow and composition data, a pump sump had been "cut-in" to the line between the second "splitter" box and Lagoon 1. (See Figure 2). Four-inch (10-cm.) diameter steel discharge lines had been installed and valved so that the manure slurry or drainage water could be pumped to either Lagoon #1 or Lagoon #2. A vertical-shaft, "non-clog", sewage pump was installed in the sump to operate on either manual or float-switch control. A clock was wired in parallel to the pump motor to indicate cumulative pumping time. The pump discharge rate was periodically determined by draw-down observations so that the product of discharge rate and daily pumping time provided volumetric loading data for the receiving lagoons. The sump was sized to accumulate approximately 800 gallons (3,000 liters) of wastes per discharge cycle. The contents could be manually mixed and sampled for data on composition when desired.

While the collection of flow data and slurry composition was significantly improved by the sump and pump arrangement, it was subject to periodic failures when the "non-clog" pump did get clogged with solids in the manure slurry. The monitoring was sufficiently good, however, to provide some reasonably accurate data on the imposed loadings and on performance for Lagoons #2, #3, and #4 during the summer of 1966. The operational results for this period have been reported in Reference 5 and will be briefly summarized here as background to the Demonstration Project being reported here. Slowly degrading solids had accumulated in Lagoon #1 to the point that virtually no free liquid volume remained

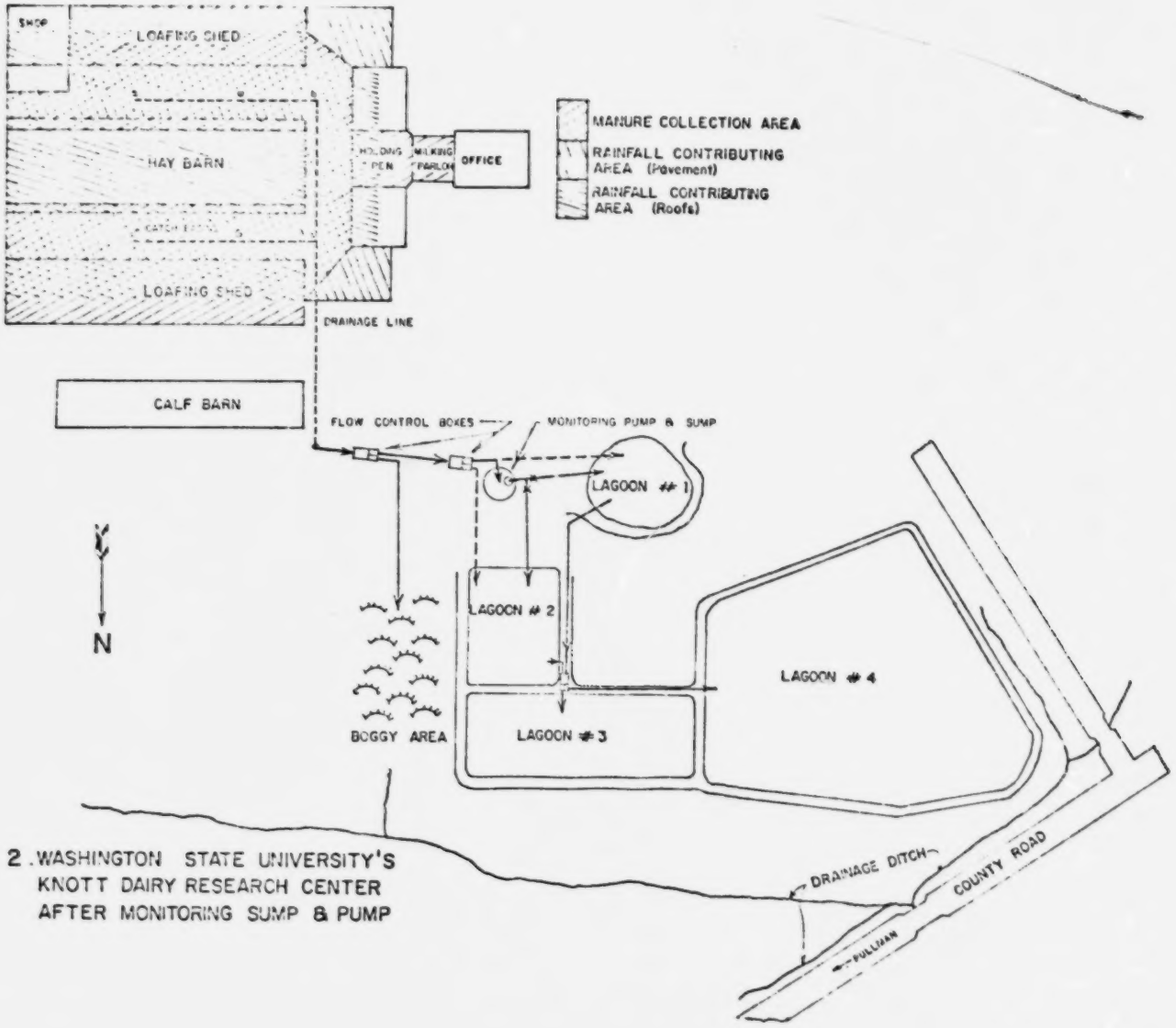

FIGURE 2. WASHINGTON STATE UNIVERSITY'S KNOTT DAIRY RESEARCH CENTER AFTER MONITORING SUMP & PUMP

at that time. A significant fraction--probably 75 percent--of the volume of Lagoon #2 was similarly filled by a thick, semi-rigid, fibrous, slowly degrading, mat of solids.

Table 1 shows the dimensions of the lagoons in operation during the summer of 1966. Approximately 4,000 gal. (15 cu. m.) per day of manure slurry was pumped to Lagoon #2. This averaged 7,500 mg./l. total solids, 5,450 mg./l. volatile solids, and 1,370 mg./l. of BOD. Average loading and performance data for Lagoon #2 is shown in Table 2. It must be remembered that Lagoon #2 contained a large accumulation of manure solids when the summer-1966 observations started. Thus a much larger mass of organic matter was undergoing degradation then just the solids in the slurry that was added during this period. Suspended solids of the added slurry were unquestionably collected by filtration through the semi-rigid mat as well as by sedimentation. It appeared that the mass of retained suspended solids remained essentially constant throughout the summer months. If so, one must speculate that previously accumulated degradable solids were being liquified and/or destroyed at approximately the same rate as resistant solids from current additions were being accumulated. Some earlier work (6) indicated that something less than 50 percent BOD removal might be achieved by sedimentation alone while 88 percent BOD removal was achieved in Lagoon #2. It must be assumed, therefore, that filtration was removing a significant amount of BOD associated with non-dissolved organic matter, and further, that such decomposition of solids was more complete than simple liquefaction. Otherwise, the effluent leaving Lagoon #2 would have been significantly stronger (the BOD removal much lower).

A slight and variable further reduction in the concentration of BOD and volatile solids occurred as the waste progressed through Lagoon #3 and accumulated in Lagoon #4. This reduction occurred even though evaporation would have had the effect of increasing concentrations as water volume decreased. The rate of liquid accumulation in Lagoon #4 accounted for less than one-third of the slurry volume added to the lagoon system during the summer. This suggests that at least 2/3 of the BOD and volatile solids discharged from Lagoon #2 was either destroyed or assimilated in settleable biomass in Lagoons #3 and #4. Essentially all of the BOD of samples from Lagoon #4 (average 200 mg./l.) could be removed by centrifugation. This would indicate that algae harvesting as a final step, if successful, would provide a high quality effluent. Actually, Lagoon #4 operated without an effluent throughout the summer after it had been drawn down by irrigation use in the spring months.

The observed results on the series of Lagoons #2, #3, and #4 were encouraging enough, even though limited, to suggest that an anaerobic lagoon with subsequent aerobic treatment would probably constitute a highly acceptable scheme for dairy manure disposal. The previously discussed criteria for success evaluation were considered. Though complete destruction of all manure solids was not accomplished, it did

Table 1

Dimensional Data on Lagoons (Summer 1966)

	Lagoon #2	Lagoon #3	Lagoon #4
Length - ft. (m.)	100 (30.5)	150 (47.5)	irregular
Width - ft. (m.)	50 (15.3)	60 (18.3)	irregular
Depth - ft. (m.)	2 to 4 (0.6 to 1.2)	3 (0.91)	3 (0.91)
Area - sq.ft. (sq.m.)	5,000 (465)	9,000 (843)	30,000 (2,790)
Total Volume - cu.ft. (cu.m.)	15,000 (425)	27,000 (765)	90,000 (2,550)
Effective Volume[1] - cu.ft. (cu.m.)	3,750[1] (106)[1]	27,000 (765)	90,000 (2,550)

[1] The effective volume of Lagoon #2 was taken as 1/4 of the total assuming that the volume was 3/4 filled by slowly degrading solids. The actual liquid, including that contained in the voids of the fibrous solids was probably nearer to 80 or 90 percent.

Table 2

Loading and Performance-Lagoon #2 (Summer 1966)

Hydraulic Loading	4,000 gal./day (15.15 cu.m./day)		
Displacement Time[1]	28 days		
Detention Time[2]	7 days		
Organic Loading			
Total Solids-Total	250	lbs./day	(114 kg./day)
Per Unit Vol.[3]	0.0167	lbs./cu.ft.-day	(0.268 kg./cu.m.-day)
Per Unit Vol.[4]	0.067	lbs./cu.ft.-day	(1.07 kg./cu.m.-day)
Volatile Solids-Total	180	lbs./day	(82.6 kg./day)
Per Unit Vol.[3]	0.012	lbs./cu.ft.-day	(0.195 kg./cu.m.-day)
Per Unit Vol.[4]	0.048	lbs./cu.ft.	(0.78 kg./cu.m.-day)
BOD-Total	45.6	lbs./day	(20.8 kg./day)
Per Unit Vol.[3]	0.003	lbs./cu.ft.-day	(0.049 kg./cu.m.-day)
Per Unit Vol.[4]	0.012	lbs./cu.ft.-day	(0.196 kg./cu.m.-day)
Performance			
Total Solids Reduction	86%		
Volatile Solids Reduction	91%		
BOD Reduction	88%		

[1] Displacement time = Total lagoon volume : hydraulic loading.
[2] Detention time = Free liquid lagoon volume (est.) : hydraulic loading.
[3] These unit organic loadings based on total lagoon volume.
[4] These unit organic loadings based on estimated free liquid lagoon volume.

appear that a very significant fraction was destroyed. The solids that did accumulate in the anaerobic lagoon, rather than being decomposed, were well contained. Ultimate disposal by land spreading could at least be accomplished on an annual or biannual basis rather than being a daily or weekly requirement. Regarding dependability, it didn't seem likely that a process failure could occur which would jeopardize the continued operation of the dairy. Though a detailed cost analysis was not possible, it appeared that any increment of lagoon operating costs would be more than compensated by a reduction in confinement area cleaning costs. Capital costs for land and lagoon construction could be significant for dairies in heavily developed municipal areas but should be quite reasonable in most rural areas. Finally, the manure disposal scheme appeared to be environmentally and aesthetically acceptable. The final product water did contain a high concentration of nutrients in the form of algae cells, however.

As consideration was given to further study or effort to evaluate treatment of manure slurries by anaerobic-aerobic processes in series, certain needs and difficulties became apparent. First, if the disposal practice was to have substantial attractiveness to the dairy industry, a study should be directed toward handling a large fraction of all confinement herd manure rather than to handling only the small fraction remaining after the confinement area was cleaned by conventional scrapers, loaders, and manure spreaders. This suggested that techniques of hydraulic flushing and pipeline transport of confinement area manure should be incorporated into the study. Secondly, the study results could have value to other dairies only if long-term, accurate data on manure slurry characteristics and process loading were obtained. This would necessitate some modification of the slurry conveyance system. Also, it seemed reasonable to assume that surface area requirements for naturally aerated aerobic lagoons would be impractical for some, if not all, dairies. A mechanically aerated facility should, therefore, be studied as a possible alternative sequential step to an aerobic lagoon. Finally, the high concentration of organic matter and nutrients in the form of algae cells in the final lagoons indicated that an attempt should be made to harvest algae as a final polishing step in the overall treatment scheme.

Undertaking a study of this nature, even with small scale facilities, would require financial resources in excess of the funds then available to either the Sanitary Engineering Section or to Washington State University. The probable applicability of results to other dairies around the region or nation made it seem appropriate to submit a project proposal to the Federal Water Pollution Control Administration. Such a proposal was submitted on November 4, 1966. A Demonstration Project Grant "Anaerobic-Aerobic Lagoon Treatment of Dairy Manure Wastes - WPD-184-01-67" was awarded, effective April 7, 1967, for a period from May 1, 1967 to April 30, 1969.

SECTION IV

PROJECT OBJECTIVES

As proposed and funded, the specific Project objectives were:

a) To demonstrate that livestock confinement areas in general--dairy cattle feed yards, holding pens, and milking parlors, in particular--can be satisfactorily and economically cleaned by hydraulic flushing and that the resulting manure slurry can be properly "managed" by degradation in heavily loaded anaerobic-aerobic lagoons.

b) To demonstrate that hydraulic cleaning and lagoon disposal need not result in either water pollution or unreasonably high water usage.

c) To determine whether it is both possible and practical to recover the nutrients, chiefly nitrogen and phosphorus, by algae culture and simple harvesting techniques.

It was assumed that if algae could be propogated and harvested, they could either be recycled back as a high protein animal feed supplement or applied to land as a source of nutrients for plant growth. Whether used for either purpose or not, the recovery of algae would reduce the nutrient content of final effluent and thus improve its quality before discharge or reuse.

SECTION V

PROJECT PLANS
FACILITIES DESIGN AND CONSTRUCTION

Manure Transport and Lagoons

Facilities existing prior to the start of this project were described in Section III - INTRODUCTION and shown in Figures 1 and 2 (pages 11 and 13). As described, the volume of Lagoon #1 had almost totally filled with accumulated, slowly degrading, manure solids from previous operations. Use of this lagoon had been discontinued and it had been completely cleaned out and refurbished. The embankment slopes had been smoothed and the bottom regraded just prior to the submission of the proposal for this project. An estimated 90,000 gallons (340,000 l.) of manure slurry and runoff water had been transferred to Lagoon #1 before the Project Award Notice had been received. Lagoon #2, which was quite shallow anyway, was full of slowly decomposing manure residues when the Project started. No attempt was made to restore it for use.

Modifications to the previously existing manure handling and treatment system consisted of:

a) Construction of a new storage lagoon for manure slurry or runoff that would be in excess of desired Project loadings;

b) Aquisition and installation of a special chopper pump for manure slurry in a new collection sump;

c) Modification of the draw-off or effluent line from Lagoon #1 including a flow regulating device and also including a provision for removing floating solids from Lagoon #1;

d) Construction of a small activated sludge facility consisting of an aeration basin, a surface turbine aerator, a final sedimentation tank or clarifier, and a sludge return pump;

e) Construction of a new shallow lagoon (Lagoon #5) for algae propagation using the activated sludge effluent;

f) Modification of Lagoon #3 to form two sequential compartments; and

g) Development of an experimental dissolved air flotation system for algae separation or harvesting.

The general arrangement of the modified facilities are shown in Figure 3.

A new manure storage lagoon was constructed near the calf barn to provide for any manure slurry in excess of the desired input to the Lagoon #1--the first stage anaerobic lagoon. While this new storage lagoon was

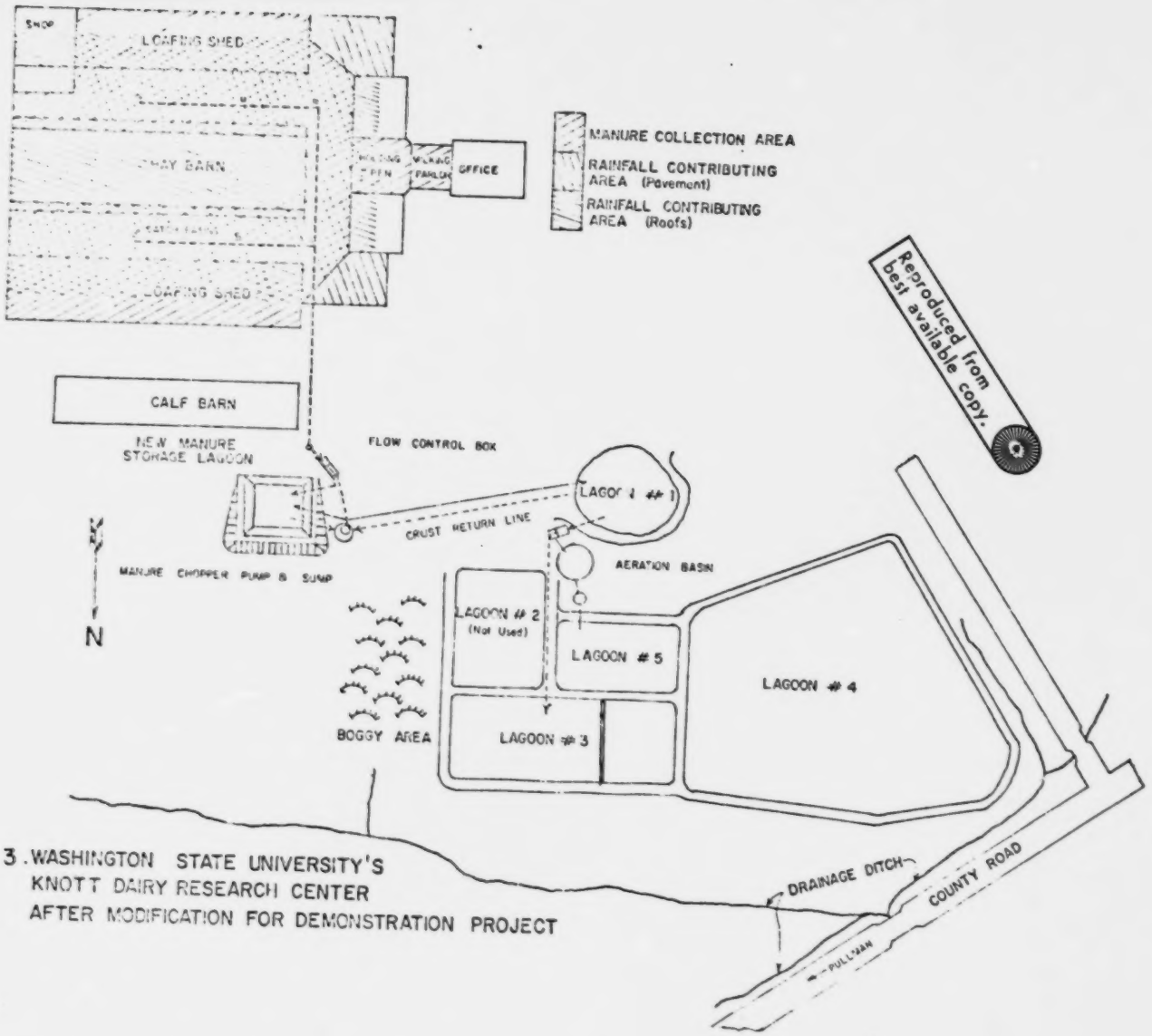

FIGURE 3. WASHINGTON STATE UNIVERSITY'S KNOTT DAIRY RESEARCH CENTER AFTER MODIFICATION FOR DEMONSTRATION PROJECT

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not built with Project funds and was not installed for Project purposes, it did materially benefit the Project by relieving the Project facilities from both excess manure slurry and from uncontrolled amounts of runoff rainfall and snowmelt water. Also, if for any reason the confinement area was not to be cleaned by flushing for a few days, slurry for desired Project loading could be withdrawn from the new manure storage lagoon. The storage lagoon dimensions were approximately 40 feet by 40 feet by 10 feet deep (12.2 m. by 12.2 m. by 3.05 m. deep).

A new sump was constructed near the new manure storage lagoon. An 8-foot (2.44 m.) long section of 9-foot (2.74 m.) diameter, asphalt coated, corrugated culvert pipe was installed with its axis vertical to form the sump walls. A 2-foot (0.61 m.) long by 3-foot (0.91 m.) diameter culvert section was then recessed into the bottom to allow a manure chopper pump to more totally empty the sump. The sump and chopper pump arrangement is sketched in Figure 4. The pump (by Vaughn Co. of Montesano, Washington) was manufactured specifically for homogenizing and pumping heavy manure slurries. The inlet end of the chopper pump bowl is shown in Figure 5. The pump impeller, just inside the twin curved inlet openings, tends to shear any stringy material entering the pump. The S-shaped piece outside of the inlet tends to break up any coarse lumps migrating to the pump inlet. As a point of interest, it was demonstrated that the pump will 'homogenize' careless tom cats as well as manure slurry.

A 12-inch (30 cm.) diameter gravity line from a flow control or diversion box in the confinement area drain line was installed to convey manure slurry directly to the chopper pump sump. Alternatively, the diversion box could be set to send the slurry to the new manure storage lagoon through an open wooden flume. A 10-inch (25 cm.) line allowed gravity transfer from the new storage lagoon to the chopper pump sump. A shear gate within the storage lagoon controlled this latter flow.

The chopper pump was equipped with a selector valve. By operating a control handle above the pump mounting base, the valve could be set to direct the pump bowl discharge to either the main discharge line or to a swiveling, rotating agitator nozzle. A second control handle allowed the agitator nozzle to be rotated about a vertical axis or angled up or down from the horizontal. The pump could thus be used to homogenize and blend the contents of the sump before pumping it to its next destination. This provided for obtaining a representative sample whenever a volume of slurry was to be transferred to Lagoon #1.

The 9-foot (2.74 m.) diameter sump contained 476 gallons (1,800 l.) per foot (.305 m.) of depth. By measuring depth before and after pumping each slurry batch, the volume of slurry pumped could be quite accurately determined.

The pump discharge line was equipped with a Tee and two quick-opening gate valves so that flow could either be directed to the new manure

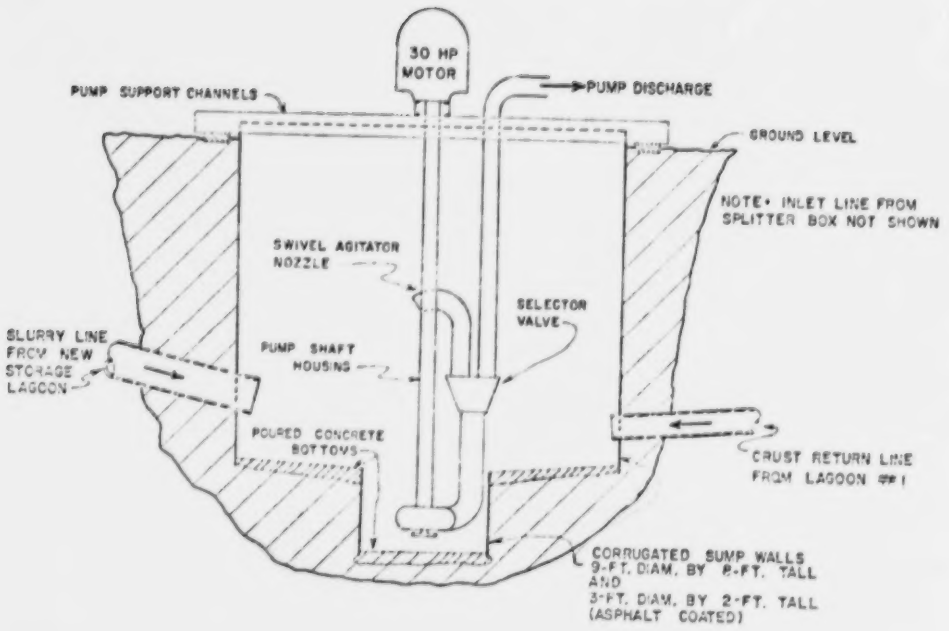

30 HP MOTOR
PUMP SUPPORT CHANNELS
PUMP DISCHARGE
GROUND LEVEL
NOTE: INLET LINE FROM SPLITTER BOX NOT SHOWN
SWIVEL AGITATOR NOZZLE
SELECTOR VALVE
SLURRY LINE FROM NEW STORAGE LAGOON
PUMP SHAFT HOUSING
POURED CONCRETE BOTTOMS
CRUST RETURN LINE FROM LAGOON #1
CORRUGATED SUMP WALLS 9-FT. DIAM. BY 8-FT. TALL AND 3-FT. DIAM. BY 2-FT. TALL (ASPHALT COATED)

Figure 4. Sketch of Chopper Pump

Figure 5. Inlet End of Manure Chopper Pump Showing Shearing Edge of Impeller

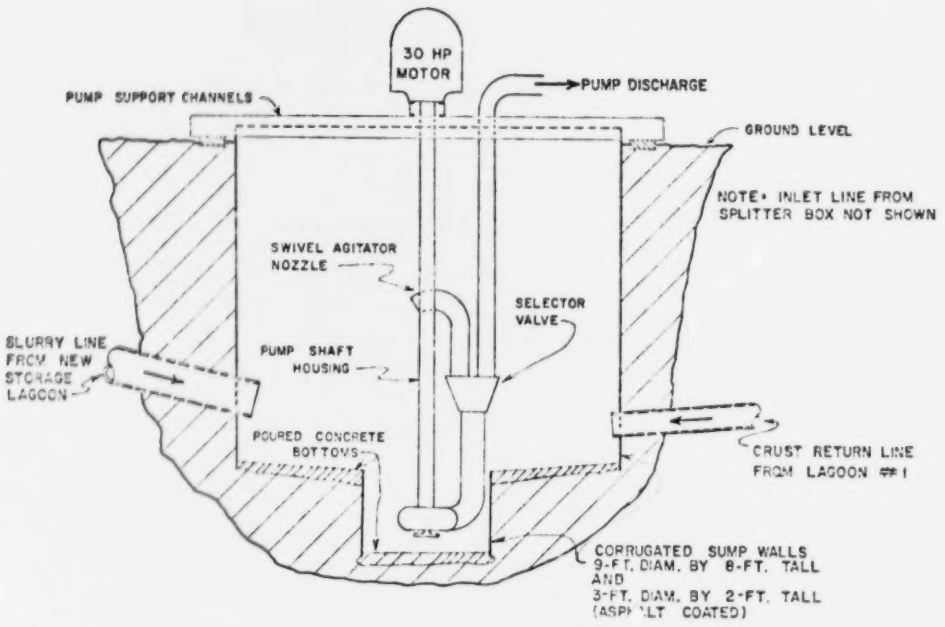


Figure 4. Sketch of Chopper Pump and Sump

Figure 5. Inlet End of Manure Chopper Pump Showing Shearing Edge of Impeller

storage lagoon or to Lagoon #1. The transport line to Lagoon #1 was a 4-inch (10 cm.) diameter steel line laid on a continuous slight upgrade to the top of the embankment of Lagoon #1. A vent valve was installed at that point and the slurry line then discharged near the center of the lagoon bottom. The vent valve allowed the line to be drained back to the pump sump, without siphoning Lagoon #1 contents during freezing weather.

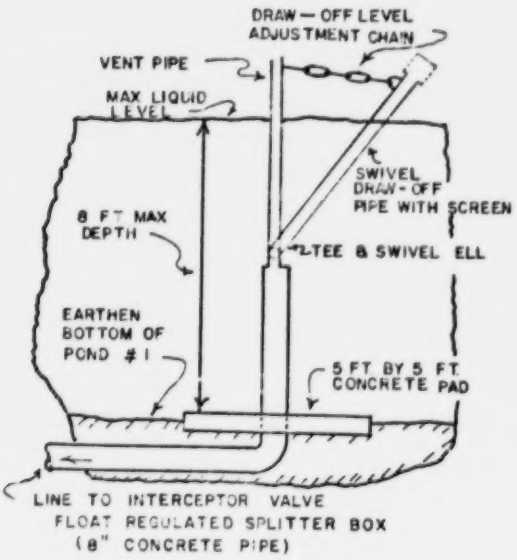
The alternate pump discharge line was connected to a 3-inch (7.6 cm.) nozzle in the storage lagoon. This provided some degree of agitation for that lagoon. Slurry could be drained from the storage lagoon into the sump and pumped back at high velocity when agitation was desired.

Lagoon #1, which was used as the first stage or anaerobic lagoon, was nearly circular in plan with a diameter of about 60 to 65 feet (19.6 to 21.3 m.) at the liquid surface level. The depth averaged 8 feet (2.44 m.). The inside embankment slopes were approximately 1 vertical to 2 horizontal. The volume was thus about 12,000 cu. ft. (338 cu. m.) or 89,000 gal. (338,000 l.). Figure 6 shows the arrangement for drawing effluent from Lagoon #1. A riser pipe extended from the outlet line in the bottom to a vent above the surface. A 2-inch (5 cm.) Tee nipple and elbow at about mid-depth on the riser allowed a draw-off pipe to swivel up and down to any desired depth. A coarse-mesh screen on the open end of the draw-off pipe prevented matted manure solids from entering the draw-off line.

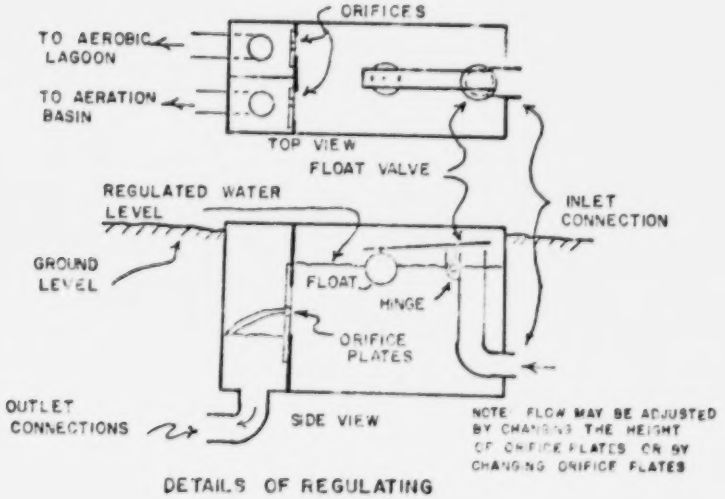
The draw-off line extended underground to a point near a regulating splitter box or flow control device. A float valve in the regulating box restricted the inflow to the box (outflow from Lagoon #1) to maintain a constant level within the box. Two orifices discharged from the constant level box to separate feed lines which extended on to secondary treatment processes.

Another feature built into Lagoon #1 was intended to provide for removal of the floating crust of solids that was anticipated in the anaerobic lagoon. A metal box with an adjustable 2-foot (0.61 m.) wide weir was installed near the shoreline of the lagoon. An 8-inch (20 cm.) concrete tile line was laid on a constant grade to extend to the manure chopper pump sump. It was intended that if and when an excessive floating crust developed, the weir could be lowered allowing the crust to skim off and flow back to the chopper pump. There, the crust would be agitated by the chopper pump and pumped back to Lagoon #1. The crust return line is indicated in Figures 3 and 4.

Again referring to Figure 3 for relative location, an aeration basin and sedimentation basin were constructed to receive a portion of the anaerobic effluent drawn from Lagoon #1. Figure 7 shows more details for this portion of the facilities. For the sake of economy, the basin was constructed below ground level with walls of posts and planks. The basin floor was packed earth. Backfill around the outside of the aeration



DETAILS OF POND # 1 DRAW-OFF



DETAILS OF REGULATING
SPLITTER BOX
(1 FT WIDE BY 25 FT LONG)
BY 15 FT DEEP

FIGURE 6. DETAILS OF DRAW-OFF AND FLOW REGULATION

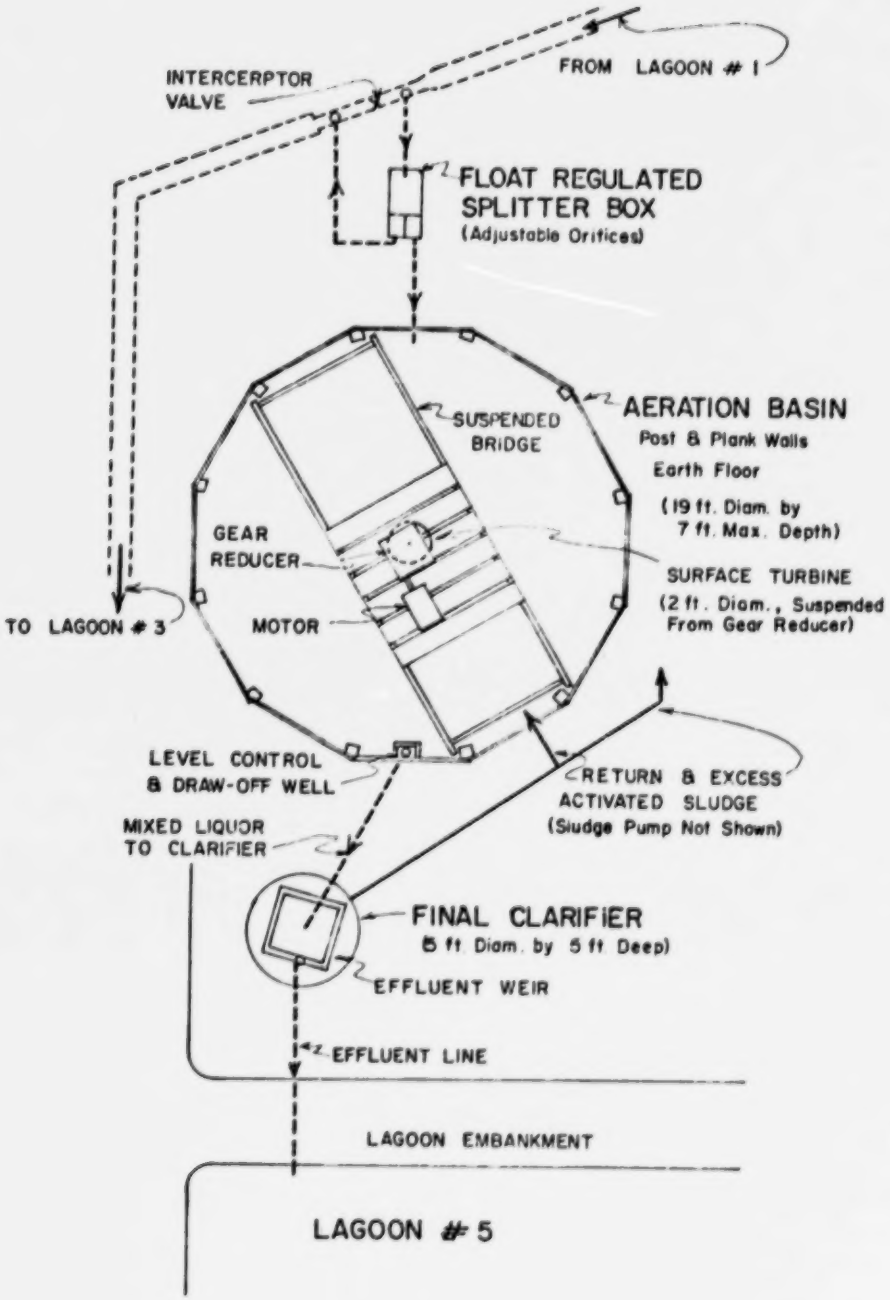


FIGURE 7. LAYOUT OF ACTIVATED SLUDGE FACILITIES

basin walls was well tamped to make the plank walls serve as a compression ring. The walls were 9 feet (2.14 m.) high to allow a maximum liquid depth of 6 feet (1.83 m.). The 'diameter' of the 12-sided basin was 19 feet (5.8 m.).

A stout wooden bridge was fabricated to be cable suspended within the basin. A surface turbine aerator, mounted on the bridge, could thus be adjusted by "reeling" the bridge up or down on its suspending cables. This arrangement allowed the basin liquid volume to be varied from 6,330 gallons at 3 feet deep (24,000 l. at 0.915 m.) to 12,660 gallons at 6 feet deep (48,000 l. at 1.83 m.).

The turbine drive assembly consisted of: (1) a worm gear speed reducer with a vertical output shaft on the bottom, (2) a Reeves-type belt drive between the input shaft of the reducer and a 3 H.P. constant speed motor, and (3) an adjustable motor mount that allowed speed adjustment through the Reeves-type belt pulleys. The turbine shaft was directly coupled to, and suspended from, the vertical output shaft of the reducer. The turbine consisted of a 2-foot (61 cm.) diameter steel disk with eight interchangeable, 3-inch by 3-inch (7.6 cm. by 7.6 cm.) square steel turbine blades attached to the bottom side only of the rotating disk. Half-inch diameter holes were drilled in the steel disk to admit air to the low pressure trailing side of each turbine blade. The turbine speed was adjustable over a range of 68 to 180 revolutions per minute.

The outlet to the aeration basin effluent line, to carry activated sludge mixed liquor to the final clarifier, was simply a vertical section of 3-inch (7.6 cm.) pipe inside a wooden stilling well on the aeration basin wall. The liquid level in the aeration basin could be raised or lowered by adding or subtracting length to the vertical pipe, the top end of which served as an overflow weir.

The final clarifier was also recessed below ground level in the hillside location. It was set so that the clarifier liquid level was below the 3-foot (0.91 m.) depth in the aeration basin. This permitted gravity flow from the aerator to the clarifier even with minimum operating volume in the aeration basin. The final clarifier was fabricated from a 5-foot diameter by 5-foot deep (1.52 m. by 1.5 m.) steel tank acquired from a junk dealer. The tank had a flat bottom so a 12-inch (30 cm.) diameter by 12-inch (30 cm.) deep sludge well was welded into the bottom. A two-armed rotating sludge scraper was fabricated and installed to move settled sludge to the sludge well. The inlet was a baffled chamber set around the central scraper drive shaft at mid-depth. A clarifier effluent launder was suspended to collect effluent at 12 equally spaced points around the clarifier liquid surface.

The clarifier scraper drive also operated a small diaphragm type sludge pump. A connection on the activated sludge return line could be used to waste excess sludge back to Lagoon #1 when desired.

A new shallow lagoon--Lagoon #5--was constructed to receive the effluent from the activated sludge process. The existing embankments of Lagoon #2, #3, and #4 constituted one side and both ends of this lagoon so earth work was only required for one side and for leveling the bottom. Since it was intended to allow photosynthetic growth of algae to take up the soluble nutrients in the activated sludge effluent, Lagoon #5 was constructed to have a liquid depth of only 16 to 24 inches (40 to 60 cm.). No effluent line was initially provided but a line was subsequently installed to allow Lagoon #5 to discharge to the largest lagoon--Lagoon #4.

The second or alternative outlet from the float regulated splitter box on the effluent line from Lagoon #1 was piped to return to the underground line that initially had gone directly to Lagoon #3. Thus, any desired fraction of the Lagoon #1 effluent could be sent to either the activated sludge system or to Lagoon #3 for treatment in the naturally aerated lagoon. Lagoon #3 was about 150 ft. (45.7 m.) long by 60 ft. (18.3 m.) wide by 3.0 ft. (0.91 m.) deep having a volume of about 27,000 cu. ft. (765 cu. m.) when filled to the point of overflow. A curtain wall of posts and lumber was erected to subdivide Lagoon #3 into two sequential cells. The initial or inlet cell had about 6,000 sq. ft. (560 sq. m.) of surface area and the second cell provided about 3,000 sq. ft. (280 sq. m.) of area. The wall was built to allow both sections to retain the same liquid level but to prevent general intermixing by wind or wave action. The second or smaller cell was intended to allow algae to grow or propogate and take up soluble nutrients remaining after aerobic treatment in the first cell.

A variable level overflow pipe allowed the smaller cell of Lagoon #3 to discharge to Lagoon #4. Lagoon #4 was irregular in shape, having a surface area of about 30,000 sq. ft. (2,790 sq. m.) and a maximum liquid depth of about 3 to 3.5 ft. (0.91 to 1.07 m.). Since it already existed, it was planned that it would be used to accumulate all treated effluent from either Lagoon #3 or Lagoon #5.

A power pole and electrical outlet (220 volt, single phase and 110 volt, single phase) were available at the common point of the embankments of Lagoons #3, #4, and #5. A pump had been located there for using the contents of Lagoon #4 for irrigation of pasture or alfalfa hay land. A small pilot scale dissolved air flotation system was developed at that point. The pressurizing pump of the flotation system was piped to take suction from any one of the three lagoons. The irrigation pump was changed to provide top horizontal discharge to prevent air binding when air was admitted in the suction line. Figure 8 schematically shows the arrangement of the pump, the air induction venturi, the air saturation tank, and the flotation tank. No provision was made for automatic float removal from the flotation tank. If the process proved successful, a float collection and removal provision would be developed and installed later.

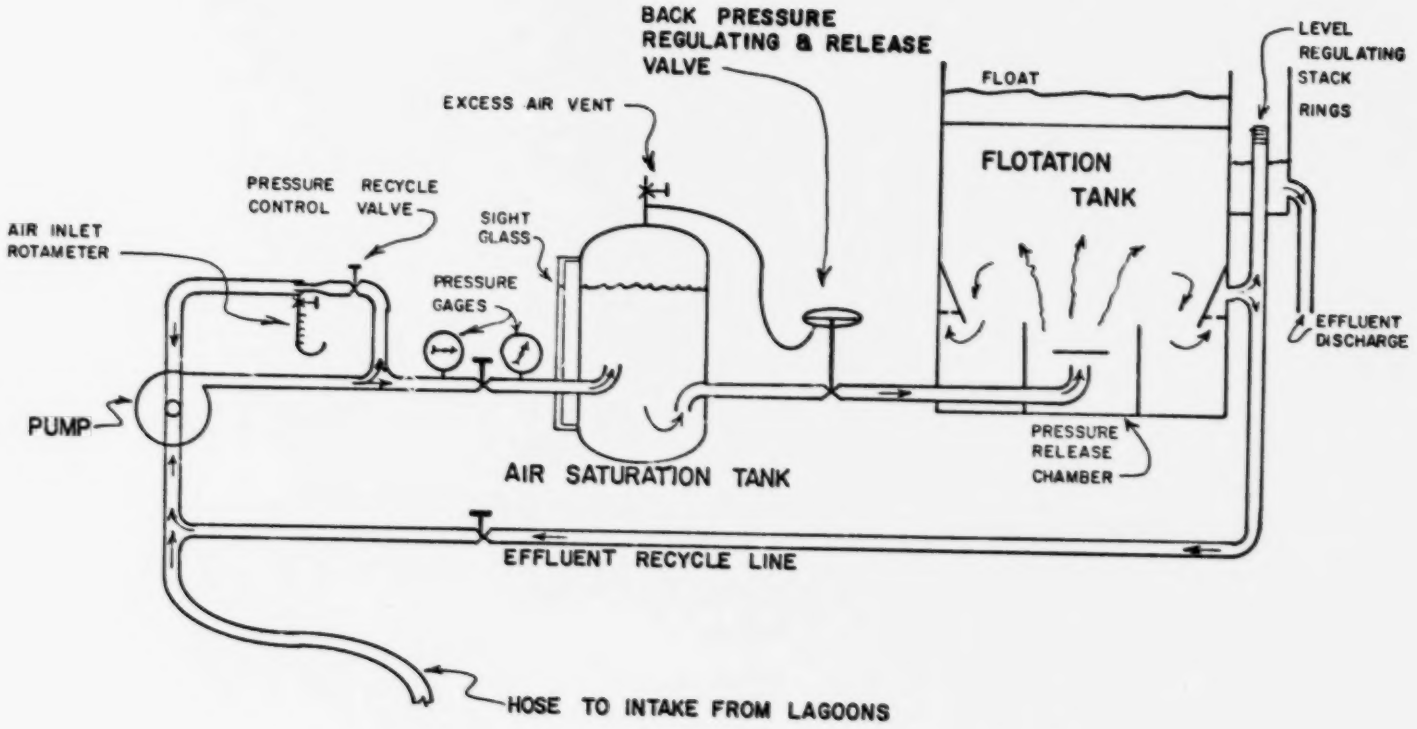


FIGURE 8. SCHEMATIC DIAGRAM OF DISSOLVED AIR FLOTATION SYSTEM.

Hydraulic Flushing

In addition to the above described modifications, alterations, and additions which were done to the previously existing manure treatment and pumping facilities, some changes were planned for the confinement area cleaning or flushing arrangements. In cleaning operations prior to the start of this Project, the bulk of the manure had been removed by conventional scrapers and loaders. The unbedded confinement areas had then been rinsed with hand-held hoses connected to the farm water supply system.

Hydraulic manure cleaning and transport would benefit both this Project and one other project then underway at the Washington State Department of Institution's Dairy Farm near Monroe, Washington. The development work on flushing methods was, therefore, considered as an essential effort in support of both projects. A description of efforts to develop hydraulic confinement area cleaning techniques has been presented in another report (4) but will be summarized here for convenience.

Since the paved cattle confinement area was already in existence at this Project site, it was considered essential that the hydraulic manure removal system be adaptable to the existing facilities. It would not be realistic to expect that other dairies would tear out and replace their existing confinement facilities in order to adopt a hydraulic cleaning procedure. As indicated in Figure 1 (page 11), the existing confinement area was equipped with an underground gravity drain system connected to several grate-covered catch basins in the open areas of the yard.

A graduate student--Mr. August C. Mueller--in the Sanitary Engineering Program (Department of Civil Engineering) at Washington State University undertook a manure flushing development study for his graduate research requirement. The objective of his work was to determine whether, and to what extent, a large number of parallel, high velocity jets, impinging on the confinement slab surface in a straight line, could clean and flush away accumulated manure. The multi-jet device, if successful, would thus serve as a "hydraulic broom" in manure cleaning operations.

It was apparent that many interrelated variables needed to be evaluated--namely: (a) the spacing and size of jet orifices, (b) the height of the orifices and angle of impingement of the jets on the slab, (c) the pressure available at the orifices, (d) the amount and physical characteristics of the manure to be removed, (e) the slope, if any, and surface texture of the confinement slab, and (f) the speed of travel or progression of the "broom". Some degree of control could be exercised over all of these variables with the exception of slab slope and surface texture.

In the first phase of development, a wheel-mounted carriage was fabricated that would permit a series of different spray bars to be installed

and tested. See Figure 9. Seven different spray bars were made. Each bar was a 4-foot (1.22 m.) long by 2-inch (5 cm.) diameter pipe with 37 holes drilled on 1-inch (2.54 cm.) centers, generating a 36-inch (.91 m.) wide flushing swath. Hole sizes provided were 2/32, 3/32, 4/32, 5/32, 6/32, 7/32, and 8/32 inches (1.59, 2.38, 3.18, 3.97, 4.76, 5.65, and 6.35 mm.). By sealing different combinations of holes, jet spacings of 1-, 2-, 3-, or 4-inches (2.5, 5, 7.6, or 10.2 cm.) could be tested. The carriage allowed the spray bars to be set at elevations of 2 to 22 inches (5 to 56 cm.) above the slab and angles of jet impingement on the slab to be varied from vertical to horizontal. Two small positive displacement fire pumps were acquired from military surplus to increase both the flow and pressure available from the farm water supply. Two 1 1/2-inch (4-cm.) diameter by 50-foot (15 m.) long sections of high-pressure hose provided the delivery connection between the pumps--operated alone, in parallel, or in series--and the spray bars.

It was generally concluded during the first phase of testing that small holes with close center-to-center spacing were more effective than larger holes having wider spacing when either slab cleanliness or water consumption was used as the criterion of effectiveness. The alignment of the row of drilled orifices was a quite critical factor in cleaning effectiveness. It was difficult to keep the two pumps running properly with the result that pressures in excess of 85 p.s.i.g. could never be maintained long enough for sustained testing.

A new spray bar was fabricated with 73 holes (1/16 inch or 1.59 cm. diameter) on 1-inch (2.54 cm.) centers. These were drilled more precisely so that all jet streams were parallel. After a few tests with this longer "broom", it appeared that significantly better results might be obtained if higher supply pressures were developed in the spray bar. A new high pressure centrifugal pump was rented that could maintain about 150 p.s.i.g. in the spray bar when 37 of the 1/16-inch (1.59-mm.) diameter orifices were operating. Working on slab areas with moderate amounts of manure, cleaning speeds of 1 to 1 1/3 feet (.3 to .4 m.) per second were possible using either 1- or 2-inch (2.5 or 5 cm.) orifice spacings. The orifices were then enlarged to 5/64 inch (2 mm.) for additional testing. With all of the enlarged orifices in operation--i.e. with 1-inch (2.5 cm.) spacing--the pump could maintain 115 p.s.i.g. in the spray bar. The best cleaning seemed to be achieved with the spray bar set 12 inches (30 cm.) above the slab and aimed at about 22 degrees below horizontal. It appeared that the slab could be quite thoroughly cleaned using about 20 gallons (75 liters) of water per cow-day.

At this point, attention was shifted to more sophisticated orifices than simple drilled holes. Several samples of different kinds of commercial nozzles were secured. A new carriage was fabricated which could be used to test different nozzles at varied spacings. See Figure 10. Also, a military surplus tank truck with a power-take-off-driven positive displacement pump was purchased. A large number of comparison tests were

Figure 9. Drilled Orifice "Hydraulic Broom" During Early Manure Flushing Experiments

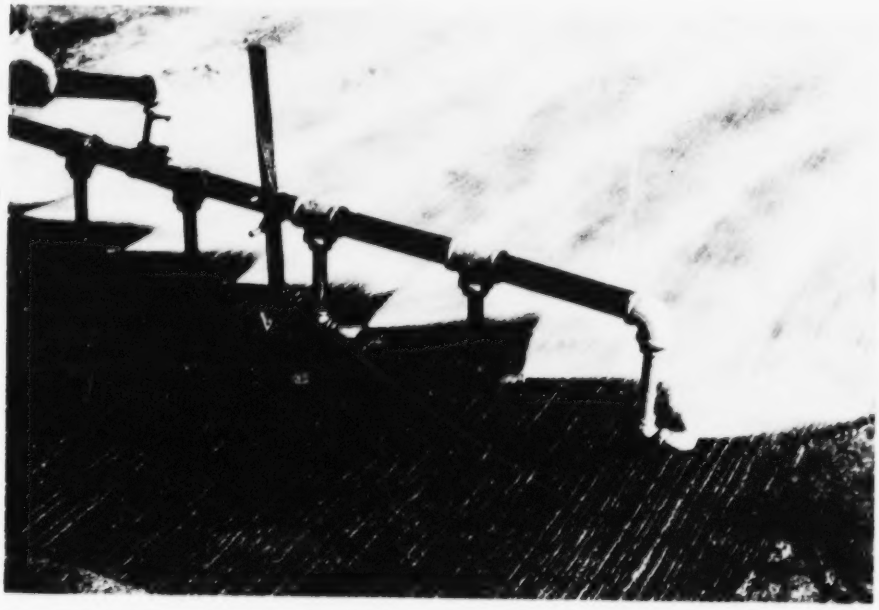


Figure 10. Second Generation "Hydraulic Broom" Pilot Model During Manure Flushing Experiments

conducted. As a result of such tests, it was found that a special V-jet nozzle was quite effective. This nozzle created a flat, fan shaped, high velocity spray.

Operating with pressures of around 200 p.s.i.g., the nozzles generated a flat, high energy, impinging spray that could effectively tear manure loose from the rough concrete surface and flush the resulting slurry along ahead of the "broom". Cleaning was more effective and faster when the accumulated manure was moist rather than dry and somewhat "caked" on the slab. An acceptable degree of cleaning was achieved, however, even on hot sunny days when much of the manure had dried to an adherent thin crust. As shown in Figure 10, eight of the V-jets were set on 10-inch (25 cm.) centers at about 3 inches (7.5 cm.) above the slab and angled downward at about 15 degrees below the horizontal. The fan-shaped sprays converged at the line of impingement about 11 to 12 inches (28 to 30 cm.) ahead of the nozzles. When the manure was moist, the "broom" could be advanced about 2.0 ft./sec. (0.6 m./sec.) and still do a thorough job of cleaning. With dry crusty manure, flushing speeds of only about 1.0 ft./sec. (.3 m./sec.) could be used. At 8 gal./min./ nozzle and nozzles on 10-inch (25 cm.) centers, this would require 0.16 gal./sq. ft. (6.5 l./sq. m.) to clean the dry crusty manure or 0.08 gal./ sq. ft. (3.25 l./sq. m.) to clean the area when the manure was moist. Assuming that 100 sq. ft. (9.3 sq. m.) of confinement area might be provided per cow, the flushing water consumption would be around 16 gal./ cow-day (60 l./cow-day) in hot dry weather or 8 gal./cow-day (30 l./ cow-day) in cool moist weather.

At this point, the "hydraulic broom" concept appeared to be quite promising. The hand-propelled test unit was very difficult to use, however, because it was necessary to overcome the powerful jet reaction and to drag along the ever-increasing length of supply hose as the "broom" was advanced. Test runs of even 25 feet (7.5 m.) would leave two men fairly well exhausted. Also, the generated manure slurry had a tendency to flow back around the ends of the "broom" and spread out over the area just cleaned. For these reasons, it was decided that a new and wider "broom" should be mounted on the tank truck as a self-propelled unit. The pressure supply pump would have to be powered independently from the truck engine in order that truck speed and pumping pressure could be individually controlled.

A gasoline fueled engine and two-stage, high pressure, centrifugal pump combination were acquired from military surplus. The unit specifications indicated that the pump would develop 290 p.s.i.g. of pressure when the flow was 450 gal./min. (1.7 cu. m./min.). The pump unit was mounted on the top of the 550-gallon (2.08 cu. m.) tank of the tank truck. A 4-inch (10 cm.) steel discharge line extended to a 3-valve manifold near the front bumper of the truck. A combination of one 7-foot (2.1 m.) long spray header on the front of the truck and an 11-foot (3.35 m.) long outrigger spray header extending out from each side provided a total spray system width of 29 feet (9 m.). Thirty of the special V-jet

nozzles were spaced on 12-inch (30 cm.) centers across the total width. A high pressure hose connected each of the three spray headers to the supply manifold.

It was anticipated that the pumping unit would probably develop at least 300 p.s.i.g. for a flow of around 330 gal./min. (1.25 cu. m./min.) through the 30 nozzles. Apparently, the specifications were not for the pumping unit obtained, however, because it could only develop 150 p.s.i.g. when only the center seven nozzles were turned on. This did not provide enough hydraulic energy to flush the manure away ahead of the broom. After about 20 feet (6 m.) of travel, a pool of manure slurry would build up and flow back through the "broom". The power-take off-driven positive displacement pump was removed from the truck and substituted for the two-stage centrifugal pump in order to develop greater pressures and more flow. It was possible to maintain pressures of about 200 p.s.i.g. on all 30 nozzles. The results were still quite disappointing, however. The truck mounted "broom" could clean the slab at about 1 1/2 ft./sec. (0.5 m./sec.) for a distance of about 30 feet (9 m.) but by then the thick slurry pool would have accumulated to the point that a hydraulic jump would develop. It would then cease to flow ahead on the slab and would eventually flood back past the "broom".

Although it was always intended that further test and development work would be done on the hydraulic broom idea, other Project priorities prevented such further effort. Unfortunately, all pictures taken of the truck rig were on two rolls of film that were lost.

SECTION VI

OPERATIONS AND RESULTS

Actual operation of the Demonstration Project could not commence until most of the modifications and additions to facilities had been planned and accomplished. The planning and construction phases of work took significantly longer than initially anticipated. The new manure storage lagoon, the chopper pump sump and the pump installation, the transfer line to Lagoon #1, the crust return line, and the minor revisions to the effluent draw-off line had been completed by late fall of 1967. Some manure slurry had then been transferred to Lagoon #1 but the amount and composition had not been determined. The settleable solids from an estimated 90,000 gal. (340 cu. m.) of slurry that had previously been placed in Lagoon #1 had not been removed when the effluent draw-off line modifications had been made.

The activated sludge facilities and other lagoon modifications were completed by May, 1968, so that actual Project operations could start. There were some minor interruptions in operations and data collection during the summer and fall periods of 1968 but, in general, operations were continuous until December, 1968. A major and significant interruption occurred then because of an extremely severe and prolonged winter.

An attempt was made, starting on May 8, 1968, to determine the composition of the contents of Lagoon #1 as a starting or reference point for operations. An unknown amount of solids existed in the lagoon. About 1,600 gal. (6 cu. m.) of new manure slurry was pumped to Lagoon #1 to increase the liquid level. The skimming weir for the crust return line was then lowered to allow Lagoon #1 liquor to flow back to the chopper pump sump. The chopper pump then discharged back to Lagoon #1. It was hoped that this circulating flow--about 900 gal./min. (3.4 cu. m./min.)--would resuspend the solids in Lagoon #1 to the point that a representative sample could be obtained. This recirculation stirring operation was continued for approximately 2 hours on May 8 and for another 6 hours on May 9 before samples were collected. The analysis of the slurry samples indicated the initial contents and composition of Lagoon #1 to be as indicated in Table 3.

The values in the three right-side columns of Table 3 represent the composition of the lagoon content samples that could not be precipitated by centrifugation at 1,000 r.p.m. for 15 minutes. No attempt was made to correct the amount values for the actual volume of centrate per unit volume of total sample centrifuged.

It subsequently became apparent that the samples of initial contents of Lagoon #1 were probably not representative. It is now felt that a very significant amount of settleable material was deposited on the lagoon bottom rather than being uniformly suspended throughout the lagoon volume at the time of sampling.

Table 3

Lagoon #1 Contents at Start of Operations
May 8-9, 1968

(Lagoon Volume = 12,000 cu. ft. = 89,000 gal. = 338 cu. m.)

	Total Composition			Centrate (Dissolved) Fraction		
	Concentration (mg./l.)	Amount (lbs.)	(kg.)	Concentration (mg./l.)	Amount (lbs.)	(kg.)
Total Solids	2640	1955	865	2155	1565	695
Volatile Solids	1410	1045	464	995	750	333
C.O.D.	1850	1370	607	1375	1020	452
B.O.D.	430	320	142	340	250	111
Total-N	197	146	64.7	176	130	57.7
Organic-N	102	75	33.3	83	62	27.1
Ammonia-N	95	71	31.1	93	69	30.6

The normal routine of operations consisted of leaving the first diversion box near the calf barn set to divert flow, should any occur overnight, to the new manure storage lagoon in the event of heavy rainfall runoff. In the morning, the flow route was changed to admit all flushing water and manure slurry to the chopper pump sump. During, or at the end of, flushing operations on the confinement yard, the chopper pump was started to agitate and homogenize the sump contents. A representative sample portion was then collected in the proportion of one milliliter of sample per gallon of slurry to be transferred to Lagoon #1. For example, if 900 gal. (3.4 cu. m.) of slurry was to be pumped to Lagoon #1, then a 900 ml. sample was collected. This sample was added to a composite sample container located in a 4°C refrigerator in the calf barn. The temperature and pH of the sumpful of slurry were observed and recorded. The level in the 9-foot (2.74 m.) diameter sump was noted. The slurry line valves were then set to pump the slurry to Lagoon #1 until the desired volume was transferred as determined by level draw-down in the sump. Any excess slurry then remaining in the chopper pump sump was then transferred to the new manure storage lagoon.

Cattle confinement yard flushing was usually done every morning except Tuesday and Friday. On these days, the manure was scraped, loaded, and hauled mechanically. Occasionally, when it was not possible to have someone present for blending, sampling, and pumping at the time of flushing, a measured volume of slurry was drawn from the new storage lagoon for transfer to Lagoon #1.

While the raw manure slurry was accumulating in the pump sump, the flows of Lagoon #1 effluent to the activated sludge process and/or to Lagoon #3 was gauged and sampled. The mixed liquor of the aerator and the return sludge from the clarifier were also sampled as was the final

effluent of the activated sludge clarifier. Volumetrically composited samples of Lagoon #1 effluent and clarifier effluent were also collected and accumulated in the refrigerator. If any adjustments in the rate of flow to the aerator and/or to Lagoon #3 were needed, the adjustments were usually made at this time.

The composite samples were returned to the laboratory on a weekly basis for analysis. Each composite sample was well mixed and divided into two portions. One portion was then centrifuged at 1,000 r.p.m. for 15 minutes to obtain a centrate portion which was considered to contain dissolved constituents only. Each of the six sample portions (i.e. raw manure slurry, raw manure slurry centrate, Lagoon #1 effluent, Lagoon #1 effluent centrate, clarifier effluent, and clarifier effluent centrate) was then normally analyzed for total solids (T.S.), volatile solids (V.S.), chemical oxygen demand (C.O.D.) by the reflux method, 5-day biochemical oxygen demand ($B.O.D._5$), organic nitrogen (Org.-N), ammonia nitrogen (NH_4-N), and total phosphate (PO_4). Additionally, the clarifier effluent was analyzed for nitrate nitrogen (NO_3-N). Spot checks revealed no nitrate nitrogen in either composite or fresh grab samples of the raw manure or Lagoon #1 effluent. Similarly, there was rarely more than a trace of ammonia nitrogen in the final clarifier effluent after the third week of operation. Alkalinity and acidity were usually determined on the uncentrifuged raw manure and Lagoon #1 effluent sample composites although such data on weekly composite samples is of questionable value.

Table 4 presents some of the data relative to the input to Lagoon #1 for the period from May 17, 1968, through December 15, 1968. The top line of data is the result of the analyses of the initial contents of the lagoon taken from Table 3. Table 5 contains similar data on the composition of the effluent from Lagoon #1 for the same period of time.

All input to and withdrawal from Lagoon #1 stopped on December 16 when an ice cover formed on the surface. The screen on the withdrawal pipe plugged up with suspended solid material and the screen could not be raised for cleaning. From that point on until late February 1969, it was not possible to resume operations. Rather than restart at that time, operations were delayed until it was possible to inventory the contents of Lagoon #1. By late March, the heavy ice cover of Lagoon #1 could be broken up.

On March 28, the skimming weir was lowered to let the contents decant back through the crust return line to the chopper pump sump where it was re-pumped back to Lagoon #1. This was continued until all floating solids had dispersed and settled. The Lagoon #1 surface area was then marked off by a grid of taut strings stretched just above the surface. The depth of the lagoon was then measured at each string intersection of the grid and the volume of each grid section determined. A piece of 3-inch (7.6 cm.) PVC pipe was then plunged from above the surface to the lagoon bottom at the center of each grid section to trap a representative portion of the contents of that section. The trapped

Table 4
Loading Data - Lagoon #1 - 1968

Time Span for Composite Samples	Slurry Volume Added (gal.)	Raw Manure Slurry Total Solids (mg/l)	Raw Manure Slurry Total Solids (lbs.)	Raw Manure Slurry Volatile Solids (mg/l)	Raw Manure Slurry Volatile Solids (lbs.)	Raw Manure Slurry C.O.D. (mg/l)	Raw Manure Slurry C.O.D. (lbs.)	Raw Manure Slurry Total Nitrogen (mg/l)	Raw Manure Slurry Total Nitrogen (lbs.)	Raw Manure Centrate (Dissolved) Total Solids (mg/l)	Raw Manure Centrate (Dissolved) Total Solids (lbs.)	Raw Manure Centrate (Dissolved) Volatile Solids (mg/l)	Raw Manure Centrate (Dissolved) Volatile Solids (lbs.)	Raw Manure Centrate (Dissolved) C.O.D. (mg/l)	Raw Manure Centrate (Dissolved) C.O.D. (lbs.)	Raw Manure Centrate (Dissolved) Total Nitrogen (mg/l)	Raw Manure Centrate (Dissolved) Total Nitrogen (lbs.)	Suspended Matter by Difference Total Solids (lbs.)	Suspended Matter by Difference Volatile Solids (lbs.)	Suspended Matter by Difference C.O.D. (lbs.)	Suspended Matter by Difference Total Nitrogen (lbs.)
Initial	89000	2640	1,955	1410	1,045	1850	1,370	197	146.0	2115	1,565	995	750	1375	1,020	176	130.0	390	295	350	16.0
05/27-05/31	5485	17010	778	12000	549	13790	631			7150	327	3870	177	7130	326			451	372	305	
06/01-06/09	7850	20120	1,317	14720	963	18370	1,203	532	34.8	6080	306	3410	223	6810	446	514	33.7	921	740	757	1.1
06/10-06/16	7765	17470	1,163	12700	843	19320	1,290	763	50.7	6230	414	3630	241	7640	507	637	42.3	746	602	783	8.4
06/17-06/23	6110	16280	830	11710	597	16940	863	714	36.4	5870	304	3440	175	6510	332	489	25.0	526	421	531	11.4
06/24-06/30	5077	17550	743	12330	522	14190	601	896	37.9	7220	306	4050	171	7510	318	742	31.4	437	351	283	6.5
07/01-07/07	6595	12710	731	8650	509	12730	732	630	36.2	5640	324	3080	177	5550	319	532	30.6	407	332	413	5.6
07/08-07/14	7540	15150	953	10650	670	12190	767	637	40.0	5940	374	3320	209	6320	398	483	30.4	579	461	369	9.6
07/15-07/21	3310	17140	488	12410	353	14360	408	686	19.5	6020	173	3410	97	6260	178	546	15.5	315	256	230	4.0
07/22-07/28	4520	22060	846	17200	648	22550	850	714	26.9	6540	247	3710	140	7860	296	448	16.9	619	508	554	10.0
07/29-08/04	7140	16240	967	11560	688	13830	823	609	36.3	5550	331	2920	174	5610	334	455	27.1	636	514	489	9.2
08/05-08/11	8537	17740	1,333	12470	887	16820	1,169	672	46.7	6120	425	3490	243	6800	473	497	34.6	908	624	696	12.1
08/12-08/18	9364	16730	1,176	11200	838	14310	1,070	662	49.5	5200	388	2890	216	5910	442	517	38.6	787	622	628	10.9
08/19-08/25	11028	19130	1,760	13500	1,279	18660	1,717	742	68.2	6710	621	4080	375	8040	739	596	54.8	1,139	904	978	13.4
08/26-09/01	10158	16830	1,428	12071	1,023	15210	1,289	652	55.2	4750	402	2800	237	6930	587	490	41.5	1,026	786	702	13.7
09/02-09/08	4840	16610	671	11770	475	16830	679	623	25.1	5110	206	2810	114	7380	298	466	18.8	465	361	381	6.3
09/09-09/15	8400	17400	1,219	12810	898	15730	1,102	617	43.2	6060	425	3500	243	7020	492	460	32.2	794	655	610	11.0
09/16-09/22	6950	11570	671	8370	485	12080	752	547	31.7	3920	227	2470	141	4590	266	409	26.0	444	344	486	5.7
09/23-09/29	7000	10420	960	11720	684	13730	801	664	38.8	6380	373	3720	217	5060	295	547	31.9	587	467	506	6.9
*05/27-09/29	127807		17,051		12,901		16,741		677.1		6,264		3,570		7,046		531.3	11,687	9,320	9,701	145.8
09/30-10/13																					
10/14-10/20	3960	17870	590	12840	425	18250	602	716	23.6	6290	208	3870	128	7770	257	547	18.1	382	297	345	5.5
10/21-10/27	6024	19650	987	14120	710	16460	827	740	37.2	6590	331	3910	197	8340	419	588	29.5	656	513	408	7.7
10/28-11/03	9257	14760	1,140	10810	837	11920	920	565	43.6	5260	422	3220	249	6410	495	460	35.5	718	588	425	8.1
11/04-11/10	8563	17310	1,293	12660	945	19000	1,420	664	49.6	6380	477	3990	298	7710	576	551	41.2	816	648	844	8.4
11/11-12/01																					
12/02-12/08	6630	18090	1,000	13140	727	13920	770	617	34.1	4820	270	2760	153	5840	323	542	30.0	730	574	447	4.1
12/09-12/15	5400	12060	543	8832	398	8510	383	427	19.2	4530	204	2650	119	4890	220	324	14.6	339	271	163	4.6
**05/27-12/15	167808		23,504		16,926		21,669		884.4		8,276		4,714		9,336		700.2	15,328	12,211	12,333	184.2
***Total Inventory	256808		25,459		17,971		23,039		1,034.4		9,841		5,464		10,356		830.2	15,718	12,506	12,680	200.2

*Total Feed between May 27 and September 29. **Total Feed Input between May 27 and December 15. ***Total Feed Input Including Contents at Start.

Table 5
Effluent Data - Lagoon #1 - 1968

Time Span for Composite Samples	Effluent Volume (gal.)	Total Effluent Total Solids (mg/l)	Total Effluent Total Solids (lbs.)	Total Effluent Volatile Solids (mg/l)	Total Effluent Volatile Solids (lbs.)	Total Effluent C.O.D. (mg/l)	Total Effluent C.O.D. (lbs.)	Total Effluent Total Nitrogen (mg/l)	Total Effluent Total Nitrogen (lbs.)	Effluent Centrate (Dissolved) Total Solids (mg/l)	Effluent Centrate (Dissolved) Total Solids (lbs.)	Effluent Centrate (Dissolved) Volatile Solids (mg/l)	Effluent Centrate (Dissolved) Volatile Solids (lbs.)	Effluent Centrate (Dissolved) C.O.D. (mg/l)	Effluent Centrate (Dissolved) C.O.D. (lbs.)	Effluent Centrate (Dissolved) Total Nitrogen (mg/l)	Effluent Centrate (Dissolved) Total Nitrogen (lbs.)	Suspended Matter In Effluent Total Solids (lbs.)	Suspended Matter In Effluent Volatile Solids (lbs.)	Suspended Matter In Effluent C.O.D. (lbs.)	Suspended Matter In Effluent Total Nitrogen (lbs.)
05/27-05/31	4400	2730	100	1340	49	2170	80			2628	96	1180	43	1640	60			4	6	20	
06/01-06/09	7920	3080	203	1560	103	2120	140	230	15.2	2760	182	1290	85	1960	129	185	12.2	21	18	11	3.0
06/10-06/16	6020	3580	180	1790	90	2630	132	258	13.0	3420	172	1680	84	2470	124	235	11.8	8	6	8	1.2
06/17-06/23	6020	3830	192	1880	94	3050	153	277	13.9	3700	186	1820	91	2560	129	258	13.0	6	3	24	0.9
06/24-06/30	6020	4020	202	1970	99	2240	112	311	15.6	3970	199	1950	98	1820	91	294	14.8	3	1	21	0.8
07/01-07/07	6020	4450	223	2130	107	3400	171	330	15.6	4220	212	2000	100	3200	161	305	15.3	11	7	10	1.3
07/08-07/14	5500	4530	208	2180	100	3310	152	341	15.6	4310	198	1910	88	3160	145	319	14.6	10	12	7	1.0
07/15-07/21	3940	4490	148	2090	69	2810	92	344	11.3	4300	141	1840	60	2600	85	325	10.7	7	9	7	0.6
07/22-07/28	6020	4550	228	2090	105	2910	146	322	16.2	4350	218	1910	96	2740	138	291	14.6	10	9	8	1.6
07/29-08/04	5970	4880	243	2090	104	3040	151	361	18.0	4640	231	2080	104	2780	138	319	15.9	12	0	13	2.1
08/05-08/11	8960	8320	622	4260	318	6730	503	451	33.7	4860	363	2180	163	3110	232	367	27.4	259	155	271	6.3
08/12-08/18	10660	5250	464	2200	194	3290	291	347	30.7	4770	422	2130	188	2970	263	323	28.6	42	6	28	2.1
08/19-08/25	9800	5430	444	2330	190	3410	279	367	30.0	5130	419	2110	172	3100	253	344	28.1	25	18	26	1.9
08/26-09/01	15100	9540	1,201	5340	674	11400	1,436	395	49.7	4020	506	1940	244	3610	455	370	46.6	695	430	981	3.1
09/02-09/08		5920		2900		5650		397		4260		1890		3240		341					
09/09-09/15	11650	7840	762	3960	385	7080	688	422	41.0	5330	516	2170	210	3310	320	364	35.2	246	175	368	5.8
09/16-09/22	14000	7790	910	3870	452	5820	680	396	46.2	4990	583	2030	237	2690	314	332	38.8	327	215	366	7.4
09/23-09/29	16700	6120	852	2960	412	4210	586	381	53.1	4950	689	2210	308	3160	440	343	47.8	163	104	146	5.3
*05/27-09/29	144640		7,182		3,546		5,792		419.8		5,334		2,373		3,477		375.4	1,849	1,174	2,315	44.4
09/30-10/13																					
10/14-10/20	12150	5010	508	2170	220	3160	320	306	31.0	4740	480	2000	203	2740	278	300	30.4	28	17	42	0.6
10/21-10/27	15370	4970	637	2210	283	3260	418	317	40.6	4740	608	2140	274	2760	354	283	36.3	29	9	64	4.3
10/28-11/03	14570	11381	1,373	6600	802	9750	1,185	351	42.7	4490	546	2030	247	3180	386	317	38.5	827	555	799	4.2
11/04-11/10	14320	5430	648	2560	306	3770	450	322	38.4	4990	595	2290	273	3150	376	297	35.4	53	33	74	3.0
11/11-12/01	4900																				
12/02-12/08	17200	8190	1,175	4440	637	8700	1,248	414	59.3	4360	625	2120	304	3080	442	338	48.5	550	333	806	10.8
12/09-12/15	12290	4800	492	2270	233	3420	351	314	32.2	4350	446	2010	206	2980	305	302	31.0	46	27	46	1.2
Total **Withdrawal	235440		12,016		6,026		9,764		664.0		8,634		3,880		5,618		595.5	3,382	2,148	4,156	68.5
Final ***Residuals	89000	27280	20,427	14285	10,699	12380	9,270	413	309.0	3350	2,508	1720	1,288	2290	1,714	278	208.1	17,919	9,411	7,556	100.9
Total Account	324440		32,443		16,725		19,034		974.0												
Total Inventory	256898		25,459		17,971		23,039		1,034.0												
Difference	67542		+ 6,984		- 1,246		- 4,005		- 60.0												

*Total Effluent Constituents from May 27 to September 29.
**Total Effluent Constituents from May 27 to December 15.
***Lagoon #1 Composition after Thaw on March 29, 1969.

contents of the pipe were then thoroughly agitated by reciprocating a disk-shaped plunger from top to bottom about 20 times. A sample of each agitated pipeful was then collected. A representative composite sample was then made up using portions of each grid sample according to that section's fraction of the total lagoon volume.

The data from analysis of this composite are shown as "Total Residuals" on the fourth-from-bottom line of Table 5. The data on the third-from bottom line--labeled "Total Account"--are the sums of all withdrawals plus the residuals. The next-to-bottom line is taken from the "Total Inventory" line of Table 4 and represents all inputs plus the amount initially determined to be present in the lagoon. Finally, the last line shows the difference between "Total Account" and "Total Inventory". Theoretically, a negative value in the "Difference" line would represent net destruction of substances in Lagoon #1 during the period of operation. Also, theoretically, there could not be a positive value in the "Difference" data but such positive values did occur.

It is known that some 42,000 gal. (160 cu. m.) of rain and snow water did enter the lagoon to partially explain the fact that there were 67,542 gal. (2.56 cu. m.) of uninventoried lagoon contents. The hillside location of the lagoon may well have intercepted a flow of groundwater during the winter months. Also, an estimated 14,000 gal. (53 cu. m.) of excess activated sludge were returned to Lagoon #1 but were not included in the inventory. These uninventoried water inputs would be partially balanced by unmeasured evaporation, of course.

The fact that there were some 6,984 lbs. (3,700 kg.) of uninventoried total solids can only be explained by an inaccuracy in the initial sampling of the lagoon contents at the start of operations. As explained earlier, the initial sampling was based on the assumption that 8 hours of recirculated pumping had re-suspended all solids. In retrospect, this seems highly unlikely and there must have been a large mass of deposited solids at the time of initial content sampling. This assumption is somewhat substantiated by the fact that nitrogen is almost balanced between account and inventory. It would have been largely in dissolved forms at the time of initial sampling and should not be destroyed or lost during the period of anaerobic lagoon operation.

If the initial total solids content determination was low because of deposited particulate solids, then the initial volatile solids and C.O.D. values would also have been low. The difference values, therefore, would also be too low. Since difference represents destruction, the actual lagoon performance was probably much better than indicated by the data of Tables 4 and 5. This speculation is more fully examined by considering the data shown in Table 6.

The speculations derived in Table 6 are probably too high in comparison to the destructions (differences) shown in Table 5 being too low. Most of the nitrogen in the manure samples was found in the centrate por-

Table 6

Speculative Data on Lagoon Loading and Performance

	Total Solids	Volatile Solids	C.O.D.	Total Nitrogen
Average Feed Strength =	$\frac{23,504 \text{ lbs.}}{167,898 \text{ gal.}}$	$\frac{16,926 \text{ lbs.}}{167,898 \text{ gal.}}$	$\frac{21,669 \text{ lbs.}}{167,898 \text{ gal.}}$	$\frac{884.4 \text{ lbs.}}{167,898 \text{ gal.}}$
X Initial Volume (89,000 gal.) = Speculative Initial Contents =	12,500 lbs.	8,980 lbs.	11,500 lbs.	469.0 lbs.
As Opposed to Table 4 Initial Contents =	1,955 lbs.	1,045 lbs.	1,370 lbs.	146.0 lbs.
Difference (Correction) =	10,545 lbs.	7,935 lbs.	10,130 lbs.	523.0 lbs.
Table 4 Inventory Amounts =	25,459 lbs.	17,971 lbs.	23,039 lbs.	1,034.4 lbs.
Corrected Inventory =	36,004 lbs.	25,906 lbs.	33,169 lbs.	1,557.4 lbs.
Table 5 Total Account =	32,443 lbs.	16,725 lbs.	19,034 lbs.	974.0 lbs.
Speculated Destruction =	3,561 lbs.	9,181 lbs.	14,135 lbs.	583.4 lbs.
Speculated % Destruction =	9.9	35.4	42.7	37.5

tions and would, therefore, have been nearly representative in the initial lagoon content samples. Only about 28% of the volatile solids in the raw manure composites was resistant to precipitation by centrifugation, however, so a significant amount could have been in bottom deposits at the time of initial sampling.

While the amount of volatile solids and C.O.D. destroyed in Lagoon #1 is quite speculative, the amount received and not passed out in the anaerobic lagoon effluent is known to a somewhat higher degree of accuracy. Whether the total inventory of volatile solids was 17,971 lbs. (8,150 kg.) or 25,906 lbs. (11,780 kg.), the effluent only carried out 6,026 lbs. (2,740 kg.). Therefore, retention and/or destruction was somewhere between 66 and 77 percent for volatile solids. C.O.D. retention and/or destruction was somewhere within the range of 57 to 71 percent. This then seems to be the principal advantage of an anaerobic lagoon for dairy manure management. The system can retain a significant fraction of the volatile matter and oxygen demanding substances while destroying only a portion of the matter retained. It does allow the ultimate disposal of the solids to be scheduled according to the season and weather conditions most acceptable to the dairy farm operator or according to circumstances advantageous for environmental quality.

It should be noted that there was no significant odor or fly problem associated with the loading and operation of the anaerobic lagoon. A heavy floating crust was anticipated but did not occur as a permanent feature during the period of May through December of 1968. Occasionally, the bottom deposit of solids would be bouyed to the surface in large, loose masses. These would generally break up and re-sink in a matter of an hour's time. A detectable, though not persistant or noxious, odor could be noticed at that time. Such "boiling" was especially noticeable during the period between August 26 and September 8 of 1968. The total solids, volatile solids, and C.O.D. concentrations of the effluent were quite high during the first week of that period as may be noted in Table 5. During the second week (09/02-09/08), the suspended fibrous solids concentration in the effluent would repeatedly plug up the effluent screen and the orifices of the effluent regulating splitter box so that accurate flow data could not be obtained. Gas trapped in the sludge again caused intense "boiling" of bottom deposits in late October and November.

The absence of data for the period of 09/30-10/13 was because of a break in the normal routine of operations. Essentially no activated sludge had been intentionally wasted (some had been lost in the clarifier effluent) up until this point. By the end of September, the activated sludge process was operating with around 8,500 mg./l. of mixed liquor suspended solids (MLSS) or 5,500 mg./l. mixed liquor volatile suspended solids (MLVSS). During the period of 09/30 to 10/13, all settled sludge from the clarifier was pumped back to Lagoon #1 rather than to the aeration basin. Because the sludge pump failed to operate for a period of unknown duration (but known to be less than 20 hours) on two different days, the

volume of excess sludge can only be estimated. It is believed that about 14,000 gallons (53 cu. m.) of this sludge were pumped to Lagoon #1 and contained some 1,400 lbs. (620 kg.) of total solids of which 700 lbs. (310 kg.) were volatile solids. The records indicate that no effluent was drawn from Lagoon #1 during this period. In retrospect, this seems highly unlikely since the return sludge volume would have caused a level increase of about 8 inches (20.3 cm.) at a time when Lagoon #1 was already full. Also, if no flow entered the aeration basin from Lagoon #1 or elsewhere during this period, the removal of 14,000 gallons (53 cu. m.) would have more than emptied the aeration basin but the basin overflow line would allow drawdown to a minimum depth of 3 feet (0.91 m.). It was later discovered that some groundwater did seep into the aeration basin throughout most, if not all, of the year. During a period of lowered liquid level in the basin, it is probable that such seepage would be quite significant. This could account for the source of the excess volume pumped to Lagoon #1.

A mass balance between influent and effluent characteristics for the aerobic processes would logically be the soundest method of evaluating performance for these processes. Such an approach would necessarily be inaccurate for this project, however. As was mentioned earlier, it was ultimately discovered that a significant, but unmeasured, flow of ground water did seep into the aeration basin. Thus, the amount of activated sludge process effluent (final clarifier effluent) was actually greater than the inflow measured at the float regulated splitter box. The effluent strength was, therefore, less than inflow strength both as a result of treatment process efficiency and because of dilution by groundwater seepage.

In spite of the dilution effect, certain conclusions can be made relative to the activated sludge process performance. Table 7 shows the average strength of influent and effluent characteristics for two periods of operation. Average pollutional strength characteristics are shown for samples as collected (weekly composites) and for certrifuged portions of the same samples. The contrast indicates the extent to which soluble and colloidal solids contributed to the total strength.

During the first period of operation, the mixed liquor volatile suspended solids increased from an initial value of less than 100 mg./l. to a nearly stable value around 3,200 mg./l. The average daily loading rate was about 855 gallons (3.24 cu. m.) of inflow containing about 3,000 mg./l. of C.O.D. during the last two weeks of this period when only minor fluctuations were noted in MLVSS concentrations. The loading rate was, therefore, around 0.085 lb. C.O.D./day/lb. MLVSS (0.085 kg. C.O.D./day/kg. MLVSS) or 16.7 lb. C.O.D./day/1,000 cu. ft. (0.69 kg. C.O.D./day/cu. m.) of aerator volume. The results were somewhat more erratic for B.O.D. tests than C.O.D. tests. Still, during this same last two weeks of the first operational period, the final activated sludge effluent ranged from 47 to 55 mg./l. of 5-day B.O.D. If it is assumed that groundwater seepage had caused a 50 percent

Table 7

Activated Sludge Process Performance

	First Period May 27 to August 4, 1968			Second Period August 5 to September 27, 1968		
Aeration Basin Depth	4.5 ft. (1.37 m.)			5.0 ft. (1.52 m.)		
Aeration Basin Volume	9,500 gal. (36 cu. m.)			10,560 gal. (40 cu. m.)		
Total Volume of Influent	57,000 gal. (219 cu. m.)			86,810 gal. (329 cu. m.)		
Average Retention Time (1)	11.3 days			6.8 days		
MLVSS Conc. (mg./l.)(2)	>100 to 3,200			3,200 to 5,500		
	Influent (mg./l.)	Effluent (mg./l.)	Reduction (%)	Influent (mg./l.)	Effluent (mg./l.)	Reduction (%)
Total Solids	4140	2560	38	6440	3840	22
(Centrate)(3)	3946	2450	38	4710	1200	47
Volatile Solids	1970	815	59	3078	1200	61
(Centrate)(3)	1830	754	59	2078	1102	47
Chemical Oxygen Demand (COD)	2832	633	78	5130	910	83
(Centrate)(3)	2580	563	78	3150	756	76
Ammonia Nitrogen (as N)	185	26		227	0	
(Centrate)(3)	173	25		213	0	
Organic-Nitrogen (as N)	116	35		180	47	
(Centrate)(3)	106	31		135	40	
Nitrate-Nitrogen (as N)	0	135		0	266	
(Centrate)(3)	0	135		0	266	
Total-Nitrogen (as N)	301	196	35	407	313	23
(Centrate)(3)	279	191	31	348	306	12
Total Phosphate (as PO_4)	271	96	65	427	154	64
(Centrate)(3)	231	70	70	314	101	68

(1) Average Retention Times would be reduced by the effect of ground water seepage into aeration basin.

(2) MLVSS is range in concentration of Mixed Liquor Volatile Suspended Solids during the time periods indicated.

(3) Parameter values indicated as (centrate) were average values after removing suspended matter by centrifugation.

dilution, the undiluted effluent strength might have been closer to 100 mg./l. of B.O.D.

For the second period of operation, the measured flow to the activated sludge process and the aerator volume were both increased. Generally speaking, the C.O.D. concentration also increased during this period because of gas bouyancy "boiling" in Lagoon #1. This increase in C.O.D. was mostly associated with increased suspended solids rather than dissolved organic matter.

During the last 12 days of this second period, the daily loading averaged about 2,560 gallons (9.7 cu. m.) of inflow containing about 4,974 mg./l. of C.O.D. (suspended + dissolved). The MLVSS concentration was reasonably steady at around 5,500 mg./l. The loading rate amounted to approximately 0.22 lb. C.O.D./day/lb. MLVSS (0.22 kg. C.O.D./day/kg. MLVSS) or 75 lb. C.O.D./day/1,000 cu. ft. (1.2 kg. C.O.D./day/cu. m.) of aerator volume. Under these conditions the effluent composite samples for both of the last two weeks contained 122 mg. B.O.D./l. Assuming that the ground water seepage was essentially constant in volume, it would be a factor of far less percentage significance during this second period of higher measured flow.

If one considers the C.O.D. reduction between the influent slurry entering Lagoon #1 and the activated sludge plant effluent, treatment efficiency was quite good. Influent slurry C.O.D. concentrations ranged from a low value of 4,950 mg./l. to a high value of 8,040 mg./l. Effluent C.O.D. concentrations averaged 633 mg./l. during the 05/27 to 08/04 period and 910 mg./l. during the 08/05 to 09/27 period. This would indicate percentage reductions in the vicinity of 85 to 90 percent for the two processes combined. The remaining organic strength of the effluent could not, however, be regarded as acceptable for direct discharge to surface waters. It would, after such treatment, still be comparable to raw sewage from many communities. Though not measured quantitatively, the color of the activated sludge effluent was always extremely high. It was never noted to be less colored than very strong tea and more normally resembled rich black coffee. At times the turbidity was quite low but this was not a consistant characteristic. The reductions in total nitrogen shown in Table 7 might well have been the effect of dilution by ground water seepage rather than being the effect of removals accomplished by the activated sludge process.

Essentially all of the effluent that could be withdrawn from Lagoon #1 during the summer of 1968 was processed through the activated sludge facilities. This did not leave enough anaerobic lagoon effluent for controlled experimental loading of the naturally aerated lagoon (Lagoon #3 of Figure 3). Only an infrequent small amount of Lagoon #1 effluent was routed to Lagoon #3 prior to September 27, 1968. Flow did enter Lagoon #3 though. The sloping hillside above Lagoon #2 did discharge any surface runoff into that lagoon which also collected direct

precipitation over its surface area. In all probability, some groundwater also seeped into this lagoon. The connection between Lagoon #2 and Lagoon #3 (See Figure 2) had not been removed so such extraneous Lagoon #2 inflow was able to flow on to enter Lagoon #3. There was no significant amount of such unplanned influent during the spring and dry summer months of 1968 but by late October 1968, such flow had rapidly filled Lagoon #3. Since this source of flow was neither metered nor sampled, it was necessary to divert it to an alternate point of disposal. A drain line was cut into the east bank to allow any water to escape into the boggy area shown in Figure 2 or 3.

Several schemes for a controlled loading for Lagoon #3 were considered for the period of 1969 following the eventual "thawing out" and resumption of operations. It was still felt desirable that most of the Lagoon #1 effluent go to the activated sludge process so that the final clarifier effluent would provide an influent to Lagoon #5 for algae propogation and harvesting experimentation. Some "supernatant" was decanted from the new manure storage lagoon to the chopper pump sump and pumped via a temporary line to Lagoon #3. This tended to cause the remaining solids in the storage lagoon to concentrate to the point that they could not be handled in the farms alternate spray irrigation system, so the practice was discontinued. Also, the quality of supernatant fluctuated over a wide range in terms of suspended matter. It was not possible to predict the strength or mass of organic matter that might be transferred to Lagoon #3 in any given batch of the storage lagoon "supernatant". When a floating scum of fibrous solids began to appear on Lagoon #3, which would interfere with natural aeration, this method of loading was discontinued. Consideration was given to reactivating Lagoon #2 as a large strainer so that slurry from the new storage lagoon could be used to generate a "leachate" for loading Lagoon #3. This would have added new putrescible matter to Lagoon #2, however, and would have introduced a new solids management problem. The accumulated residues remaining from 1967 use of Lagoon #2 were well stabilized by then. It was decided that Lagoon #2 should be allowed to continue to revert to a dry stable soil condition since it was totally covered by vegetation at that time. Ultimately, the decision was to concentrate all project effort on algae propogation and harvesting rather than to continue any attempt to evaluate the naturally aerated lagoon as a sequential step to anaerobic lagoon treatment. Even the modest organic loading that had been accumulated in Lagoon #3 was sufficient to maintain anaerobic conditions throughout all but the upper 3 to 6 inches (7.5 to 15 cm.) for most of the summer of 1969. Grass and weeds growing just above the waterline drooped over into the water unless they were mowed and removed quite frequently. Eventually, the contents of Lagoon #3 were pumped back to the new storage lagoon for dilution of accumulated solids and applied as irrigation water to nearby fields.

In spite of the limited experimentation with Lagoon #3, it was reasonably apparent that as a naturally aerated lagoon operating in sequence with

an anaerobic lagoon it would contribute very little to the solution of manure management problems at the Dairy Research Center.

The installation of the facilities for dissolved air flotation harvesting of algae was essentially completed around August 1, 1968. Initially, no provision was made for measuring the rate of air admission to the suction side of the pressurizing pump. With the pump primed and operating, the air saturation tank pressure could be adjusted to any desired pressure up to 65 p.s.i.g. or lower. The back pressure regulating and release valve could be adjusted to the desired pressure and the process flow rate adjusted by by-passing flow from the discharge to the suction side of the pump. When air was admitted to the pump, however, the pump efficiency would drop and flow through the impeller was reduced. Apparently, air could then accumulate in the impeller and the pump would lose "prime". The system seemed to be unstable in that the pump would lose "prime" quite readily whenever any adjustment was made to the setting on the backpressure valve, the pump by-pass or recycle valve, or to the air inlet valve.

On August 10, a small gear-type positive displacement pump (gasoline engine driven) was substituted for the centrifugal pressurizing pump. This eliminated the problem of losing "prime" when adjustments were made. The throttle on the gear pump engine was arbitrarily set to pump an estimated 12 gallons per minute at a saturation tank pressure of around 40 to 45 p.s.i.g. The air admission rate was not known or even estimated. With no coagulant feed or pH adjustment of any kind, the algae cell suspension (from Lagoon #5) was floated quite successfully. The raw feed was quite green and turbid indicating a rich algae concentration. The process effluent was almost clear with only a slight tint of green indicating a very good harvesting efficiency. It did appear that the brown color of the activated sludge process effluent (influent to Lagoon #5) had been quite effectively removed by the algal growth. The process float was quite thick, having a consistancy best described as "thin green pea soup". The upper surface of the float would deaerate rapidly and seemed to dry to a greenish brown organic crust in a matter of only a few minutes. The float was stable enough, however, to be scraped to screeded from the flotation tank surface with nothing more sophisticated than a piece of wooden lath. The process effluent was conveyed by hose back to Lagoon #5. Flotation of the algae was so good that even the small amount of air supersaturation remaining in the process effluent started to cause a thin green float to develop on the surface of Lagoon #5

The above described operation of August 10 was, in effect, only a mechanical shakedown of the process equipment. No quantitative attention was given to the process. pH was not measured; samples for laboratory analysis of raw feed, process effluent and float were not collected; the air flow rate was not even estimated; and the liquid flow rate was not carefully controlled or measured. This was quite unfortunate because it was never again possible, either in the

remainder of 1968 or during the spring and summer of 1969, to obtain results even remotely close to the success of August 10, 1968.

The engine driven gear pump did eliminate the air binding problem but was quite noisy, was difficult to start, and was so old that it could hardly be expected to last through many days of process testing. Piping modifications were made to introduce air through a venturi constriction on the discharge side of the electric-motor-driven centrifugal pump. This, plus the addition of an air flow indicator, eliminated the problems of losing "prime" of the pump during operational adjustments.

After the above modifications were made, approximately three days of additional operating attempts at dissolved air flotation of algae were made in late August and early September. These tests were without the use of any chemical additions. The very best performance during these tests would have to be chassified as very poor. Float formation was either non-existant or so unstable that it could not be skimmed from the surface of the flotation tank. Visual comparisons of color and turbidity of influent and effluent samples did not indicate any reduction in algae cell concentration. Neither increasing or decreasing the air flow rate resulted in improved performance. No further pilot scale tests were conducted in 1968. Some laboratory batch tests were performed but these were also unproductive.

In June 1969, both laboratory batch tests and pilot scale field tests were resumed. With the exception of a few brief transitory periods, even fair harvesting results could not be achieved unless coagulants and/or pH adjustments were made. On July 8, 1969, it was possible to recover a skimmable float with a suspended volatile solids concentration ranging from 0.7 to 1.4% by weight. The raw feed suspension from Lagoon #5 contained about 675 mg./l. of suspended (centrifugally removable volatile solids consisting chiefly of Euglena, Scenedesmus, and Chlorella. Even though a reasonably thick float was recovered, the effluent suspended volatile solids were only about 15% lower than the influent concentration. In effect, the float concentration was good but harvesting efficiency was still not good.

Laboratory tests using coagulants, coagulant aids, and pH adjustments were erratic and not reproducible from one day to the next. Various combinations of aluminum sulfate, ferric chloride, ferric sulfate, ferrous sulfate, sodium hydroxide, bentonite, and proprietary coagulant aids were used in coagulation-flocculation jar tests. These tests were observed for speed of floc formation, floc strength or fragility, floc settling rates, and clarity of the bulk liquid phase after settling. Those chemical addition dosages that gave good results were then repeated in a laboratory dissolved air flotation test cell and observed for flotation efficiency after air saturation at 40 to 45 p.s.i.g.

Though several chemical dosage combinations resulted in good floc formation as judged by floc strength, floc settling rates, and bulk phase clarity, no combinations were found that could produce good dissolved air flotation results with field samples from either Lagoon #4 or #5. With rich concentrations of laboratory reared Chlorella cultures, pH values of 10.3 or above, and various dosages of ferric chloride, bentonite, and polyelectrolytes, it was possible to achieve good separation in batch flotation tests. Similar results could not be achieved with field samples of algae suspensions, however.

The pilot scale dissolved air flotation facilities did not provide for pre-flocculation treatment of algae suspensions which could then be floated by air saturated recycled effluent. It was possible, though certainly not demonstrated, that pre-flocculation and a pressurized recycle mode of operation might have been successful.

It is not possible to explain why the rather crude shakedown operations of August 10, 1968, had been so completely successful and all subsequent concerted efforts were so totally unproductive. This writer is still of the opinion, totally unsubstantiated by observed results, that algae propogation and dissolved air flotation harvesting may be a practical method for removing nutrients from aerobically treated waste waters. This must be recognized as an opinion and not a conclusion reached as a result of this project.

SECTION VII

REFERENCES

1. Loehr, Raymond M., "Animal Wastes - A National Problem," Journal of the Sanitary Engineering Division - American Society of Civil Engineering, Vol. 95, No. SA 2, pp. 189-221 (1969).

2. Mehren, George L., "Aesthetics, Economics - Animal Wastes," Proceedings, National Symposium on Animal Waste Management. ASAE Publication No. SP-0366, pp. 4-7 (1966).

3. Proctor, Donald E., "The Management and Disposal of Dairy Manure," Proceedings of the 23rd Purdue Industrial Waste Conference, pp. 554-566 (1968).

4. Proctor, Donald E., "Dairy Manure Management Methods," A technical report on a Solid Waste Demonstration Project soon to be published as an NTIS report.

5. Bhagat, Surinder K., and Proctor, Donald E., "Treatment of Dairy Manure by Lagooning," Journal of the Water Pollution Control Federation, 41, No. 5, Part 1, pp. 785-794 (May 1969).

6. Proctor, Donald E., "Amounts, Composition, Characteristics and Pollutional Properties of Animal Manures," Proceeding of the Pacific Northwest Animal Industry Waste Conference, Washington State University, Pullman, pp. 21-27 (1964).